Influence of Regional Pollution Outflow on Particle Number Concentration and Particle Size in Airshed of Guangzhou, South China

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ABSTRACT

A measurement campaign of particle number concentration and size distribution was conducted at urban (SYSU) and suburban (Panyu) areas of Guangzhou, South China, during 16 January to 3 February 2020 before and during the Chinese New Year (CNY) holiday. Average particle number concentration (PNC) was $6.3 \times 10^3$ cm$^{-3}$ and $9.7 \times 10^3$ cm$^{-3}$, respectively, at urban and suburban sites, indicating the severe particulate matter (PM) pollution. The PNC in the region was influenced by monsoon and the land–sea breeze systems. During monsoon seasons, PM pollution occurred at a regional scale affecting the urban and suburban areas as indicated by the high PNC correlation ($r$ value = 0.70), but the PNCs were lower than that during land- sea breeze period (with lower PNCM1/PNCLSB1 and PNCM2/PNCLSB2 ratios) due to the higher atmospheric dispersion. There is a strong local emission (mainly vehicular emissions) in both urban and suburban areas which was significantly lowered during the CNY period due to reduced human activities. The PM pollution was found to be significantly influenced by local emissions (dominated by Aitken mode particles) and new particle formation (NPF) process (dominated by nucleation mode particles). NPF event was found to be associated with a higher N$_{10-25}$/H$_2$SO$_4$ proxy ratio during the low wind speed condition.

Keywords: Particle number concentration, Size distribution, Megacity, Regional pollution, New particle formation

1 INTRODUCTION

Atmospheric particulate matter (PM) has severe adverse impacts on human health and climate change (Charlson et al., 1992; Donaldson et al., 1998, Myhre, 2009) which is of great concern to the public. Fine particulate matter is known to be associated with respiratory and cardiovascular diseases (Nel, 2005), and ultrafine particles (UFPS, $d \leq 100$ nm) may cross the blood-brain and alveolar-capillary barriers and enter the central nervous system (Oberdörster and Utell, 2002).
Furthermore, PM can alter the climate forcing by scattering and absorbing solar radiation through aerosol-radiation interactions (ARI), and also uptake water vapor to act as cloud condensation nuclei (CCN) which then alters cloud albedo and precipitation through aerosol-cloud interactions (ACI) (Boucher et al., 2013). Conventionally, in the context of developing air quality guidelines, mass concentrations of PM such as PM$_{2.5}$ and PM$_{10}$ were used as indexes for pollution levels (e.g., WHO, 2006). Numerous studies of PM$_{2.5}$ and PM$_{10}$ were conducted in past decades to investigate their physicochemical properties, sources, health effects and pollution control in technical and policy regulation aspect (Chan and Yao, 2008). In recent years, it has been found that there is a strong association between elevated particle number concentrations (PNCs) and vehicle emission influenced environments such as roadside, on-road, and tunnels (Morawska et al., 2008). As UFPs attribute to more than 80% of total particle number concentration (Morawska et al., 2008; Cheung et al., 2016), there is an increasing concern about UFPs in recent years due to its adverse impacts on human health, and this leads to the introduction of vehicle emission standards for PNCs, such as European VI (ICCT, 2016) and China 6 (MEP, 2016) emission standards.

Due to the rapid economic and industrial developments, China has gained enormous economic growth over the past decades, which has resulted in a large increase in emissions of air pollutants, contributing to deteriorating regional air quality in China (He et al., 2002; Cheung et al., 2005; Chan and Yao, 2008; Fu et al., 2016). The Pearl River Delta (PRD) region, including megacities such as Guangzhou, Shenzhen and Hong Kong, are important economic hubs in China which contributed to about 9% of the total gross domestic product (GDP) of China in 2019 (GPBS, 2019; NBSC, 2019). Guangzhou, the capital city of Guangdong Province, situated in the Pearl River Delta (PRD) Region, South China (see Fig. 1), has over 15 million population and is the most densely populated megacity (GPBS, 2019) in southern China. Many previous studies have been conducted to characterize the physicochemical properties of PM$_{2.5}$ and PM$_{10}$, and its source apportionment in PRD region which provide scientific information for local government to formulate an effective regulation for air quality improvement (e.g., Fu et al., 2014, 2016; Xie et al., 2020). The air quality in the PRD region was significantly affected by the meteorological conditions, for example, continental outflow.

![Fig. 1. Locations of sampling sites: urban monitoring site at Sun Yat-sen University (SYSU), Guangzhou (circle); suburban monitoring site at Panyu (PY), Panyu (triangle).](image-url)
pollution was dominated under the influence of winter monsoon, and low wind speed associated with the land-sea breeze circulation may lead to poor air quality (Ding et al., 2004; Fan et al., 2008). Only a few studies were available on the influence of synoptic circulation on PNC (e.g., Cheung et al., 2016; Sebastian et al., 2022). The influence of meteorological conditions on the air masses and atmospheric dilution was found to be highly varied on each study sites (Bousiotis et al., 2021). Notably, the PNCs in urban areas in the PRD region was found to be mainly affected by the intense traffic emissions (Yue et al., 2013). New particle formation has significant contribution to the PNCs (Liu et al., 2008). However, previous PM studies conducted in the PRD region mainly focused on the characterization of fine particulate matter, such as their physiochemical properties, formation process, source apportionment, and their implications on visibility (Wang, 2003; Hagler et al., 2006; Wu et al., 2013). Hussein et al. (2009) investigated the regional new particle formation (NPF) events in Finland and Southern Sweden, and the results showed that the regional NPF can significantly affect the accumulation mode particle concentration by the particle growth of newly formed particles. In addition, Cheung et al. (2012) reported that the influence of regional NPF events which occurred at upwind areas can significantly influence the PNC at downwind suburban area. These studies both demonstrated that the PNC not only affected by local emissions but also by regional sources. However, studies on UFPs in the PRD region, especially on the spatial variations of PNCs among different locations, are still limited (Liu et al., 2008; Yue et al., 2013). To further investigate the implication of transport of the local and regional pollution of UFPs and the associated new particle formation (NPF) process in the megacity, field measurements of particle number concentration and size distribution were conducted at two locations (approximately 30 km apart) which represent upwind urban region and downwind semi-urban region in winter season during 16 January to 3 February 2020. As part of the control measures of COVID-19 pandemic, China imposed nationwide restrictions on travel and required its people to stay home (lockdown) and shutting down commercial activities beginning in late January 2020 (Huang et al., 2021; Wang et al., 2020). Chinese New Year (CNY) holiday commenced on 25 January 2020 and were extended until 9 February in Shanghai, Suzhou, Guangdong Province, Zhejiang Province, Jiangsu Province, and Yunnan Province to prevent mass movement of citizens (China Briefing, 2020). There were minimum human activities in these areas in Guangzhou and its surrounding areas during this period. This study investigated the temporal variation of PNC and particle size distribution in Guangzhou under the influence of winter monsoon circulation, as well as the changes of PNC due to a significant suppression of economic activities during the lockdown period. The impacts of NPF on the PNCs at the study region were also evaluated. We firstly present the overall PNC and size distribution and compare our data to those obtained from other urban regions around the world. We then examine the temporal variations of PNC in megacity of Guangzhou, the influence of environmental parameters (i.e., meteorological conditions and existence of other pollutants) on PNC and the correlation between two sites in a mesoscale airshed. Finally, we examine the influence of NPF on the PNC in an urban megacity, and the influence of sulfuric acid using H2SO4 proxy and wind speed on NPF events.

2 METHODOLOGY

2.1 Site Description

Field measurements of particles and gaseous pollutants were conducted at two locations in Guangzhou during 16 January to 3 February 2020, to represent the urban and semi-urban environments. Fig. 1 illustrates the sampling location of urban site at rooftop of the eight-floor campus building at Sun Yat-sen University located in Haizhu District of Guangzhou (SYSU, 23.10°N, 113.30°E), and semi-urban site at rooftop of the building of Bureau of Ecology and Environmental Protection at Panyu, approximately 25 km southeast from the central city area of Guangzhou (PY, 22.94°N, 113.37°E). The SYSU site is situated in the center of Guangzhou which is primarily affected by vehicle emissions as Guangzhou was known to have one of the highest traffic in China (16.5 million daily traffic) (Zhao and Moh, 2005), and the PY site is situated in the suburban areas of Panyu, dominated by local light industrial and domestic emissions. Panyu is one of urban districts of the prefecture-level city of Guangzhou. It was a separate county-level city before its incorporation into modern Guangzhou in 2000.
2.2 Particle Size Distribution

Particle size ranging from 10 to 480 nm was measured by a scanning mobility particle sizer (SMPS) system, which consisted of two parts: i) an electrostatic classifier (TSI 3082, TSI Inc.) for particle sizing, and ii) a butanol-based Ultrafine Condensation Particle Counter (CPC) (TSI 3756, TSI Inc.) was used to measure particle concentration at SYSU site. The manufacturer-stated particle size measurement range of the TSI 3756 CPC is 2.5 nm to > 3000 nm, with ±10% accuracy and a response time of < 1 s for 95% response (TSI, 2018). Air sample was drawn from the rooftop through 4.5 m long stainless-steel tube (1 inch OD) with 16.7 L min⁻¹ flowrate to indoor laboratory, and the air stream subsequently passed through a 1.5 m conductive tube (3/8 inch ID) with 3.1 L min⁻¹ flowrate connected with a Nafion™ diffusional dryer prior to a flow splitter at 0.3 lpm for PSD measurement by the SMPS (1 m long conductive tube, 1/4 inch ID) and a bypass air flow of 2.8 L min⁻¹ connected to other equipment for a collaborating project which is outside the scope of this study. The SMPS system was operated with the sheath and aerosol flow of 5 L min⁻¹ and 0.3 L min⁻¹, respectively. The system flow rates were checked before and after the sampling period. Multiple charge and diffusion loss corrections (inside SMPS instrument) were applied to the PSD measurements using the internal algorithm from the Aerosol Instrument Manager Software. Furthermore, diffusion loss in sampling tube was corrected according to the algorithm proposed by Holman (1972). The time resolution for the PSD data was 5 mins, and the total PNC (N_{10-480}) was calculated by integration of particle number concentration for each size bin from SMPS data for SYSU site. Particle number concentration at Panyu site (PY) was measured by a water-based Condensation Particle Counter (MAGIC 200, Aerosol Devices Inc.) which measures particles with diameter from 5 to 2500 nm. Since the PNCs for two sites were obtained from different instruments with different size ranges, caution should be taken when comparing the PNC between these two sites. Nevertheless, the temporal variations and correlations between the PNCs of SYSU and PY sites are still representative for Guangzhou regional air quality.

2.3 Gaseous Pollutants and Meteorological Parameters

Complementary gaseous pollutants such as O₃, SO₂, CO and NOₓ concentration data were obtained from the monitoring stations of Bureau of Ecology and Environmental Protection at Haizhu Park station (HZP, 23.08°N, 113.33°E), approximately 4 km to SYSU site, and Daishi station (DS, 23.02°N, 113.30°E) 13km to PY site. The synoptic meteorological conditions and gaseous data at HZP and DS were representative of those at SYSU and PY site, respectively. It was noted that since no solar radiation data is available at HZP, a Reanalysis Shortwave Solar Radiation (SSR) data of ERA5 dataset from European Centre for Medium-Range Weather Forecasts (ECMWF) was used to represent the solar radiation at SYSU site for the estimation of particle production by photochemical reaction.

During the measurement period, two synoptic wind circulations were affecting the study area. One is the winter monsoon which associated with the northerly winds along with high barometric pressure and decrease of ambient temperature, another is the land-sea breeze (LSB) circulation associated with the southeasterly winds from coastal region due to colder air masses at land during the nighttime and early morning which change to southeasterly winds when the air masses on land become warmer during daytime than that in the Pearl River Estuary (Fan et al., 2008). The Monsoon period is classified as the period under the continuous influence of northerly winds with gradually increase of barometric pressure and decrease of temperature until the changing of above conditions. The LSB period is defined as the time when wind direction changes diurnally during daytime and nighttime. Thus, two winter monsoon periods (M) were classified (i.e., M1: 16 January 12:00 LT–20 January 23:00 LT, and M2: 25 January 11:00 LT–31 January 12:00 LT) and two land-sea breeze (LSB) periods (i.e., LSB1: 21 January 00:00 LT–25 January 10:00 LT (LSB1), and LSB 2: 31 January 13:00 LT–3 February 11:00 LT) were identified in this study. The classification of M1, M2, LSB1 and LSB2 are based on the wind directions as illustrated in Fig. 2. The SYSU site is located in the upwind area (see Fig. 1), which is affected by the strong northerly winds (as represented by HZP station) whereas at the downwind PY site, the north westerly winds were dominant (as represented by DS station), during the winter monsoon periods (i.e., M1 and M2). The synoptic wind patterns of HZP site were influenced by land-sea breeze circulation with the easterly/southeasterly winds dominated in morning and changed to northeasterly wind in the
evening (see Fig. 3). The LSB circulation observed at DS site was less significant. Nevertheless, during the non-monsoon periods, the wind speeds were significantly lower than those during monsoon periods and a distinct difference can be observed. The variations of pressure and temperature provide additional information on the influence of winter monsoon to southern China during the period of M1 and M2 (see Fig. 1).

2.4 Data Processing and Analysis

Particle number concentrations for different size ranges were calculated by the PSD from SMPS measurement. The particle number concentrations were classified into $10 \leq d \leq 480 \text{ nm (N}_{10-480})$, $100 < d \leq 480 \text{ nm (N}_{100-480})$, $25 < d \leq 100 \text{ nm (N}_{25-100})$, and $10 \leq d \leq 25 \text{ nm (N}_{10-25})$, for total, accumulation mode, Aitken mode and nucleation mode, respectively. For graphical representation, time resolution of 5 min was used for particle data, whereas the data for trace gases and meteorological parameters were hourly based. Thus, the 5-min PNC and PSD data were then calculated into hourly averages for data comparison and analysis purposes.

3 RESULTS AND DISCUSSION

3.1 Overall PNC at Guangzhou and its Temporal Variations

3.1.1 General statistics of PNC over Guangzhou and comparison with other major cities

The average PNC concentrations measured in this study ($6.3 \times 10^3 \text{ cm}^{-3}$ at SYSU; $9.7 \times 10^3 \text{ cm}^{-3}$ at PY) were comparable to that measured in urban and suburban areas Guangzhou city which has indicated that traffic as the major PM pollution source ($16.0 – 29.0 \times 10^3 \text{ cm}^{-3}$) (see Table 1) and that measured in other major cities in China, including Shanghai ($17.6 \times 10^3 \text{ cm}^{-3}$) and Nanjing ($19.5 \times 10^3 \text{ cm}^{-3}$), and Milan ($18.7 \times 10^3 \text{ cm}^{-3}$) in Italy. Nevertheless, the PNC measured at the two sites in the present study were comparable to that in urban cities, such as Los Angeles.
Fig. 3. Time series of PNC, PM$_{2.5}$ and gaseous pollutant concentrations of O$_3$, SO$_2$, CO and NO$_x$, measured during the measurement period. Color code: HZP (red line) and DS (blue line) (Chinese New Year holiday commenced on 25 January and extended to 9 February 2020).

Table 1. Particle number concentration measured at different locations in China and other major cities in the world.

<table>
<thead>
<tr>
<th>Locations</th>
<th>Site Setting</th>
<th>Sampling period</th>
<th>Size range (nm)</th>
<th>PNC (cm$^{-3}$)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guangzhou (Sun Yat-sen University)</td>
<td>urban</td>
<td>16 Jan–3 Feb 2020</td>
<td>10–480</td>
<td>$6.3 \times 10^3$</td>
<td>This study</td>
</tr>
<tr>
<td>Panyu (PY), China</td>
<td>sub-urban</td>
<td>16 Jan–3 Feb 2020</td>
<td>5–2500</td>
<td>$9.7 \times 10^3$</td>
<td>This study</td>
</tr>
<tr>
<td>Guangzhou, China</td>
<td>urban</td>
<td>Jul 2006</td>
<td>20–10000</td>
<td>$29.0 \times 10^3$</td>
<td>Yue et al. (2013)</td>
</tr>
<tr>
<td>Guangzhou (Back-garden), China</td>
<td>rural</td>
<td>Jul 2006</td>
<td>3–10000</td>
<td>$17.0 \times 10^3$</td>
<td>Yue et al. (2013)</td>
</tr>
<tr>
<td>Shanghai, China</td>
<td>urban</td>
<td>Jan–Dec 2013</td>
<td>13.6–2500</td>
<td>$17.6 \times 10^3$</td>
<td>de Jesus et al. (2019)</td>
</tr>
<tr>
<td>Nanjing, China</td>
<td>urban</td>
<td>Jan–Dec 2012</td>
<td>6–800</td>
<td>$19.5 \times 10^3$</td>
<td>de Jesus et al. (2019)</td>
</tr>
<tr>
<td>Milan, Italy</td>
<td>urban</td>
<td>Mar 2015–Feb 2016</td>
<td>4–1000</td>
<td>$18.7 \times 10^3$</td>
<td>de Jesus et al. (2019)</td>
</tr>
<tr>
<td>Los Angeles, U.S.</td>
<td>urban</td>
<td>Aug 2014–Jul 2015</td>
<td>13.6–736.5</td>
<td>$8.3 \times 10^3$</td>
<td>de Jesus et al. (2019)</td>
</tr>
<tr>
<td>Brisbane, Australia</td>
<td>urban</td>
<td>Dec 2013–Nov 2014</td>
<td>5–1000</td>
<td>$8.0 \times 10^3$</td>
<td>de Jesus et al. (2019)</td>
</tr>
</tbody>
</table>

(8.3 $\times 10^3$ cm$^{-3}$) in the U.S. and London (8.5 $\times 10^3$ cm$^{-3}$) in the U.K, but higher than that in Brisbane (8.0 $\times 10^3$ cm$^{-3}$) in Australia. The PNC levels at urban and suburban Guangzhou were shown comparable to other urban cities in the world which are susceptible to PM pollution.

3.1.2 Temporal variations of meteorological, gaseous pollutants and particulate matter

During the measurement period, air pollutants such as O$_3$, SO$_2$, CO, NO$_x$ and PM$_{2.5}$ in Guangzhou were significantly affected by meteorological conditions as shown in Fig. 3. The data of gaseous
pollutants and PM$_{2.5}$ at Haizhu Park (HZP, 23.08°N, 113.33°E) station (approximately 4 km from SYSU site) and Dasha (DS, 23.02°N, 113.30°E) station (approximately 10 km from PY site) were used to represent the ambient concentrations at urban and suburban Guangzhou, respectively. Both stations are operated under the air monitoring quality network of Bureau of Ecology and Environmental Protection, Guangdong Province. The concentrations of primary pollutants NO$_x$ and SO$_2$ were significantly lower during the two monsoon periods (i.e., M1 and M2) compared to the LSB periods (i.e., LSB1 and LSB2) at HZP and DS, while M2 (from 25 to 31 January), which occurs during the CNV period, is seen to have lower NO$_x$ and SO$_2$ than M1 (from 16 to 21 January) (see Table 2). During the monsoon, the averaged concentrations for NO$_x$ and SO$_2$ were 34.3 and 3.5 µg m$^{-3}$, respectively in M1 and 11.3 and 2.3 µg m$^{-3}$, respectively in M2 at HZP; and were 26.5 and 6.5 µg m$^{-3}$, respectively in M1 and 9.6 and 4.9 µg m$^{-3}$, respectively in M2 at DS which showed a substantial decrease of these primary pollutants (by 67.1 and 34.3%, for NO$_x$ and SO$_2$ respectively, at HZP and by 63.8 and 24.6%, for NO$_x$ and SO$_2$ respectively, at DS) during the CNV period. It was reported that a sharp reduction of NO$_x$ was observed (> 60%) for China after the COVID-19 lockdown commenced (Huang et al., 2021). The limited human activities, such as shutting down of factories and restriction on travel has resulted in a general decrease in gaseous emissions. Similarly, there were a decrease of 32.9% in the averaged concentrations of NO$_x$ and a slight increase of 2.4% of SO$_2$ at HZP in LSB2 during the CNV period, and a corresponding decrease of 36.2 and 20.3% at DS. It can be seen that there was generally a sharp decrease in primary emissions. Although primary emissions have been reduced, secondary emissions of pollutants such as O$_3$ and PM$_{2.5}$ in M2 increased during the CNV period. The reduction of NO$_x$ and increase in O$_3$ observed in this study coincided with the results reported in Huang et al. (2021). In the cold season where the incident solar radiation is weak, NO$_x$ concentration decreases significantly influenced O$_3$ concentrations by suppressing the scavenging of O$_3$ through NO$_x$ titration (Jhun et al., 2015). This has resulted in the increase of O$_3$ which eventually enhanced the atmospheric oxidation capacity and production of secondary PM (Huang et al., 2021). In addition, NO$_x$ and SO$_2$ during M2 period (during the CNV period) were lower than those in LSB2 (at both HZP and DS), indicating that in addition to the dispersion effect from strong monsoon in M2, significantly low concentration of PM precursors in the period also attributed to lower PNC in urban and suburban Guangzhou during the CNV period. This will be discussed in detail in later section.

Fig. 4 and Table 3 show the distinct variations in PNCs for four periods. For the whole sampling period, the average PNCs measured at SYSU and PY were $6.3 \times 10^3$ cm$^{-3}$ and $9.7 \times 10^3$ cm$^{-3}$, respectively. During the measurement campaign, the monsoon and land sea breeze circulation systems both affected urban Guangzhou and Panyu before and during the holiday. This study hence provides an insight into the estimation of the relative influence of regional pollution transport associated with winter monsoon vs local pollution, and also the reduction of primary emissions has been reduced, secondary emissions of pollutants such as O$_3$ and PM$_{2.5}$ in M2 occurred during the CNY period, is seen to have lower NO$_x$ and SO$_2$ than M1 (from 16 to 21 January) (see Table 2). During the monsoon, the averaged concentrations for NO$_x$ and SO$_2$ were 34.3 and 3.5 µg m$^{-3}$, respectively in M1 and 11.3 and 2.3 µg m$^{-3}$, respectively in M2 at HZP; and were 26.5 and 6.5 µg m$^{-3}$, respectively in M1 and 9.6 and 4.9 µg m$^{-3}$, respectively in M2 at DS which showed a substantial decrease of these primary pollutants (by 67.1 and 34.3%, for NO$_x$ and SO$_2$ respectively, at HZP and by 63.8 and 24.6%, for NO$_x$ and SO$_2$ respectively, at DS) during the CNV period. It was reported that a sharp reduction of NO$_x$ was observed (> 60%) for China after the COVID-19 lockdown commenced (Huang et al., 2021). The limited human activities, such as shutting down of factories and restriction on travel has resulted in a general decrease in gaseous emissions. Similarly, there were a decrease of 32.9% in the averaged concentrations of NO$_x$ and a slight increase of 2.4% of SO$_2$ at HZP in LSB2 during the CNV period, and a corresponding decrease of 36.2 and 20.3% at DS. It can be seen that there was generally a sharp decrease in primary emissions. Although primary emissions have been reduced, secondary emissions of pollutants such as O$_3$ and PM$_{2.5}$ in M2 increased during the CNV period. The reduction of NO$_x$ and increase in O$_3$ observed in this study coincided with the results reported in Huang et al. (2021). In the cold season where the incident solar radiation is weak, NO$_x$ concentration decreases significantly influenced O$_3$ concentrations by suppressing the scavenging of O$_3$ through NO$_x$ titration (Jhun et al., 2015). This has resulted in the increase of O$_3$ which eventually enhanced the atmospheric oxidation capacity and production of secondary PM (Huang et al., 2021). In addition, NO$_x$ and SO$_2$ during M2 period (during the CNV period) were lower than those in LSB2 (at both HZP and DS), indicating that in addition to the dispersion effect from strong monsoon in M2, significantly low concentration of PM precursors in the period also attributed to lower PNC in urban and suburban Guangzhou during the CNV period. This will be discussed in detail in later section.

Table 2. Average gaseous concentration (C) measured at HZP and DS during different measurement periods; and the ratios of C$_{M2}$/C$_{M1}$, C$_{M1}$/C$_{LSB1}$, and C$_{LSB2}$/C$_{LSB1}$, C$_{M2}$/C$_{LSB2}$.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Whole period</th>
<th>M1</th>
<th>M2</th>
<th>LSB1</th>
<th>LSB2</th>
<th>C$<em>{M2}$/C$</em>{M1}$</th>
<th>C$<em>{LSB2}$/C$</em>{LSB1}$</th>
<th>C$<em>{M1}$/C$</em>{LSB1}$</th>
<th>C$<em>{M2}$/C$</em>{LSB2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO$_x$ HZP</td>
<td>29.8 ± 25.9</td>
<td>34.3 ± 12.9</td>
<td>11.3 ± 5.2</td>
<td>41.6 ± 34.9</td>
<td>31.5 ± 24.8</td>
<td>0.33</td>
<td>0.76</td>
<td>0.82</td>
<td>0.36</td>
</tr>
<tr>
<td>NO$_x$ DS</td>
<td>20.9 ± 14.9</td>
<td>26.5 ± 11.4</td>
<td>9.6 ± 5.6</td>
<td>26.3 ± 19.4</td>
<td>23.9 ± 9.5</td>
<td>0.36</td>
<td>0.91</td>
<td>1.01</td>
<td>0.40</td>
</tr>
<tr>
<td>SO$_2$ HZP</td>
<td>3.7 ± 2.8</td>
<td>3.5 ± 2.6</td>
<td>2.3 ± 1.0</td>
<td>4.1 ± 1.2</td>
<td>4.2 ± 1.4</td>
<td>0.66</td>
<td>1.02</td>
<td>0.85</td>
<td>0.55</td>
</tr>
<tr>
<td>SO$_2$ DS</td>
<td>5.9 ± 2.2</td>
<td>6.5 ± 1.3</td>
<td>4.9 ± 1.5</td>
<td>6.4 ± 2.6</td>
<td>5.1 ± 2.4</td>
<td>0.75</td>
<td>0.80</td>
<td>1.02</td>
<td>0.96</td>
</tr>
<tr>
<td>O$_3$ HZP</td>
<td>53.0 ± 33.6</td>
<td>35.6 ± 21.7</td>
<td>58.5 ± 24.9</td>
<td>58.1 ± 41.8</td>
<td>66.5 ± 41.6</td>
<td>1.64</td>
<td>1.14</td>
<td>0.61</td>
<td>0.88</td>
</tr>
<tr>
<td>O$_3$ DS</td>
<td>70.5 ± 31.7</td>
<td>51.2 ± 22.0</td>
<td>73.6 ± 27.0</td>
<td>73.0 ± 35.6</td>
<td>95.2 ± 31.7</td>
<td>1.44</td>
<td>1.30</td>
<td>0.70</td>
<td>0.77</td>
</tr>
<tr>
<td>CO HZP</td>
<td>0.5 ± 0.2</td>
<td>0.8 ± 0.2</td>
<td>0.5 ± 0.2</td>
<td>0.4 ± 0.2</td>
<td>0.4 ± 0.1</td>
<td>0.67</td>
<td>0.88</td>
<td>1.85</td>
<td>1.41</td>
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<tr>
<td>CO DS</td>
<td>0.6 ± 0.2</td>
<td>0.8 ± 0.1</td>
<td>0.6 ± 0.2</td>
<td>0.6 ± 0.2</td>
<td>0.5 ± 0.1</td>
<td>0.70</td>
<td>0.83</td>
<td>1.32</td>
<td>1.11</td>
</tr>
</tbody>
</table>

Note: C$_{M1}$, C$_{M2}$, C$_{LSB1}$ and C$_{LSB2}$ are the gaseous pollutant measured during M1, M2, LSB1 and LSB2 period, respectively.
higher. By comparing the PNCs measured during two monsoon periods (i.e., M1 and M2) and LSB periods (i.e., LSB1 and LSB2), the influences of regional pollution transported from upwind region of Guangzhou on PNCs compared to that by the influence of local pollution can be estimated. Notably, the ratios of $P_{NCM2}/P_{NCM1}$ and $P_{PNCLSB2}/P_{PNCLSB1}$ at SYSU were 0.33 and 0.76 (reduced by 66.7% and 24.1%), indicating a substantial reduction in PNCs during the holiday, especially under the strong dispersion conditions during the monsoon period. On the contrary, a ratio of $P_{NCM2}/P_{NCM1}$ of 0.52 (reduced by 48.3%) at PY site also indicated the substantial reduction of PNCs during the holiday in suburban Guangzhou under the impact of monsoon. On the other hand, a ratio of $P_{PNCLSB2}/P_{PNCLSB1}$ of 1.16 (increased by 15.7%) at PY indicated the PNC obtained at downwind suburban region of Guangzhou was higher during the normal LSB circulation before the holiday. PM pollution was generally found to be significantly reduced during the CNY holiday with less impact from regional pollution. This indicates that both the reduction in local emissions from Guangzhou (primarily from vehicular emissions) and as well as those from the surrounding cities have impacted the PM level. Furthermore, it was noted that the relatively higher PNC during LSB2 (during the CNY holiday) at PY was due to an elevated PNC (a maxima value $3.9 \times 10^4$ cm$^{-3}$ of PNC in this study) observed on 31 January. We found that there is an NPF event occurred on that day. Hence, the higher average PNC observed at PY is related to the NPF event and will be discussed in the next section.

### 3.1.3 Diurnal variation of PNC

As shown in Fig. 5(a), the diurnal variations of PNC at SYSU site and PY site were consistent, in which a bimodal distribution pattern was depicted with a smaller peak occurred at noon (12:00 LT)
and a larger peak occurred in the evening (18:00–19:00LT). In addition, a small peak of PNC was observed in the morning (07:00–08:00 LT) which coincided with the peak of NOx indicating the influence of vehicular exhaust emissions during the rush hours (Morawska et al., 2008). The noon peak of PNC resembled that of SSR, indicating that from 10:00 LT to noon, as the SSR increased, photochemical rate increased, leading to the increase of the formation rate of new particles (Kulmala, 2003), until the noon peak was reached at 12:00 LT. The concentration of NOx rose from the lowest value in the afternoon (i.e., 15:00 LT) to a daily maximum at 23:00 LT. However, the peak of PNC at around 19:00 LT did not correspond to that of NOx. This will be further discussed in detail below.

Using the particle size distribution data at the SYSU site, the PNC was divided into three groups according to the particle size, namely N10-25 (nucleation mode), N25-100 (Aitken mode) and N100-480 (accumulation mode). From the diurnal variations of these three groups of PNCs in Fig. 5(b), it can be seen that N25-100 was the highest among the three types of particles for most of the day, indicating that the study area is affected by as severe ultrafine pollution dominated by Aitken mode particles. This showed that the study area is affected by as severe ultrafine pollution dominated by Aitken mode particles. Although N10-25 was lower than other larger particles during the entire measurement period, its increasing rate during 05:00–10:00 LT was higher than that of N25-100 and N100-480 (see Fig. 5(b)), inferring that more nucleation mode particles (N10-25) were produced. This phenomenon has also been found in previous studies where an NPF event started before noontime and in turn enhanced the formation of nucleation mode particles (Cheung et al., 2011; Liu et al., 2008). The impact of NPF events on the PSD at SYSU will be discussed in Section 3.2.3. The maxima of PNCs for different particle sizes occurred in different time periods: the peak of N10-25 appeared at 18:00 LT, and the peaks of N25-100 and N100-480 appeared at 19:00 LT. After the peak at 19:00 LT, N100-480 subsequently plateaued (see Fig. 5(b)). Note that the particle size distribution in the atmosphere changed significantly after the evening period at 19:00 LT, and N25-100, which originally accounted for the largest proportion in PNC dropped sharply. This can be explained by the particle growth processes and the condensation of condensable gas precursors in the atmosphere (Kerminen et al., 2018). Smaller particles in the atmosphere tend
to coagulate with larger particles and produce larger particles which leads to significant decrease of concentrations of smaller particles (N_{10-25} and N_{25-100}) as shown in the diurnal variation of PM$_{2.5}$ with a peak at about 21:00 LT (Fig. 5(b)) and a flat downward trend of N$_{100-480}$. The large number of N$_{25-100}$ dominates PNC, which caused PNC to drop rapidly after its peak in the evening, despite of the increase in NO$_x$ (from vehicular exhaust) as observed earlier. In addition to the above reasons, the night peak of PNC may be related to both the mixing layer height and evening traffic peak hours. In addition, lower temperature leads to a lower mixing layer, resulting in weaker dispersion of ground pollutants (Tang et al., 2016). According to the diurnal temperature variation (Fig. 5(b)), the temperature in Guangzhou dropped after 16:00 LT. As a result, the mixing layer height also dropped, causing the PNC to rise until it peaked at 19:00 LT.

3.2 Association of Synoptic Wind Patterns with PNC and NPF

3.2.1 Correlation among PNC within urban airshed under monsoon and land-sea circulations

In this section, correlation analysis was conducted for the hourly averaged PNC between SYSU and PY sites. We first compare the correlation of PNCs of the two datasets during the entire period. Their correlation before and during the CNY period will also be assessed. Finally, we select the period during which Guangzhou area is affected by the monsoon (M1 and M2) to compare the correlation of PNCs between the two sites under the land-sea breeze circulations (LSB1 and LSB2).

Fig. 6(a) depicts the scatterplot of PNCs between SYSU and PY, with the Pearson coefficient of 0.60 ($p < 0.001$), showing a moderate correlation of PNCs between these two sites. This result indicated that the ambient PNC in Guangzhou region was a regional pollution issue for Guangzhou despite the large distance of approximately 30 km. This is also supported by similar r values in the plots between the PNCs at the two sites for the period before (0.57, $p < 0.001$) and during (0.50, $p < 0.001$) the CNY holiday (Fig. 5(b)). During the CNY holiday (beginning at 00:00 LT on 25 January), a sharp reduction of primary emissions occurred in Guangzhou as indicated by significant low concentrations of NO$_x$ and SO$_2$ which has been discussed in Section 3.1.2. We further examined the correlation of PNCs between SYSU and PY before the CNY (16 January–24 January) and after the holiday (25 January–3 February). Despite the similar correlation between the two sites during the two periods, a significant reduction of PNC was also observed for urban Guangzhou (SYSU) (as indicated by smaller slope value of 0.30 during the CNY holiday compared to 0.49 before the holiday in the regression line Fig. 6(b)) revealed that there is a greater reduction of primary emissions (e.g., vehicular emissions) in urban Guangzhou during the CNY holiday than that in suburban areas.

To further investigate the influences of monsoon and land-sea breeze circulations on regional PNCs of Guangzhou, Pearson correlation coefficients ($r$) between the scatterplots of PNCs at SYSU and PY sites were calculated for monsoon period (combined M1 and M2), and LSB period (combined LSB1 and LSB2) (Figs. 6(c) and 6(d)). For monsoon periods, the $r$ value is 0.70 ($p < 0.001$) a slightly higher than that for whole period ($r = 0.60$) (Figs. 6(a) and 6(c)) which implied the stronger influence of particle emission sources from upwind urban site (i.e., SYSU) to downwind suburban site (i.e., Panyu) under the northerly winds during the monsoon periods. In contrast, the $r$ value is weaker (0.30, $p < 0.001$) during land–sea breeze periods (Fig. 6(d)) which implied that the PNCs at both sites were primarily attributed to local emissions. Due to the occurrence of NPF on January 31, there was a high PNC concentration measured at PY. If this is treated as an outlier, the Pearson coefficients become 0.58 ($p < 0.001$) by excluding the data point on that day (Fig. 6(d)).

3.2.2 Correlation among PNC and other environmental parameters

In this section, the effect of other environmental parameters on the PNC observed at urban (SYSU) and suburban (PY) areas is studied. Table 4 summarized of the PNC under different wind speed and direction. Obviously, the lower wind speed was found to be associated with the higher PNCs at both at SYSU and PY sites which suggested the effect of weak atmospheric dilution. The wind speed for different wind directions were hence calculated (see Table 4). For SYSU site, the higher wind speed was observed in northerly wind (270–315 degree) and northeasterly (0–45 degree). In contrast, lower wind speed was observed in the northerly wind (0–135 degree). This result showed the stronger influence of winter monsoon at the upwind urban site (SYSU)
compared with that at downwind suburban site (PY). We further investigate the PNC under different wind direction for two sites. Highest PNC (i.e., $12.6 \times 10^3$ cm$^{-3}$) was obtained under the wind direction (225–270 degree) in urban site, while highest PNC (i.e., $10.0 \times 10^3$ cm$^{-3}$) was obtained under the wind direction (0–45 degree) in suburban site. Similar observations for NO$_x$ were obtained where higher NO$_x$ observed under southerly wind in urban, and higher NO$_x$ observed under northerly wind in suburban, respectively. These finding showed that the different variation patterns of PNC at SYSU and PY sites were obtained under the influence of the winter monsoon.

Fig. 6. Scatterplots between the PNCs of SYSU and PY for (a) whole measurement period, (b) before and during COVID lockdown periods, (c) monsoon period and (d) land-sea breeze periods. Data on 31 January is excluded in (d). Color marker indicated the corresponding date for the data points.
3.2.3 Characteristics of NPF events in urban Guangzhou

In urban environment, atmospheric particles were dominated by Aitken mode particles associated with vehicle emissions (Morawska et al., 2008). Elevated PNC was well observed in urban environment when NPF occurred which caused an increase in PNC of nucleation mode particles to several times higher than that influences by vehicle emission sources, and the nucleation mode particles that can further grew to larger sizes than that from vehicle emissions (Cheung et al., 2013). An NPF event is defined as the substantial increase of the number concentration of nucleation mode particles, which can further grow to Aitken and/or accumulation mode size range (≥25 nm) and last for a few hours until they disappear into the atmosphere by condensation/coagulation sinks (Dal Maso et al., 2005). To investigate the influence of primary and secondary sources on particle number concentration in urban Guangzhou, we analyzed the temporal variations of PNC and size distribution measured at SYSU. A total of six NPF events were identified during the measurement periods, and the particle formation rate ($J_{10-25}$) and growth rate (GR) for the NPF events on 18 January, 20 January and 31 January were calculated (Table 5), while the $J_{10-25}$ and GR were unclear for other NPF events (i.e., 28 January, 29 January and 30 January). Following the method by Dal Maso et al. (2005), the particle growth rate (GR) was calculated for NPF days by fitting the geometric mean diameter (GMD) starting from the initial stage of NPF event until the particle size grows beyond the size of 25 nm and the particle formation rate ($J_{10-25}$) was calculated as the sum of the apparent formation rate (dN$_{10-25}$/dt) and the coagulation loss rate during the NPF event. The averaged GRs were found to be 14 nm h$^{-1}$ (7.0–21.0 nm h$^{-1}$), comparable to those reported in previous studies in the PRD region (J$_3$: 0.5–5.2 cm$^{-3}$ s$^{-1}$, for 3–30 nm particles), likely due to the difference in particle size range among measurements. In this study, the particle size can be measured down to 10 nm, while a lower limit of 3 nm was employed in previous studies in the PRD region, which theoretically should have higher formation rate under similar atmospheric conditions. Furthermore, similar results have been observed in urban Taiwan which was 11.9 nm h$^{-1}$ on average and ranged from 4.4–38.7 nm h$^{-1}$ (Cheung et al., 2013), and other urban areas with median GR of 5.9 nm h$^{-1}$ (Kerminen et al., 2018). Sulfuric acid is usually considered as a precursor of new particles, especially in urban environments (Weber et al., 2001). To evaluate the contribution of sulfuric acid to the particle production, a $\text{H}_2\text{SO}_4$ proxy was used as an indicator of nucleation formation.

Table 4. Averaged PNC observed at SYSU and PY associated with different wind direction. The NO$_x$ and wind speed data for SYSY and PY were measured at HZP and DS stations.

<table>
<thead>
<tr>
<th>WD</th>
<th>PNC ($10^3$ cm$^{-3}$)</th>
<th>NO$_x$ (µg m$^{-3}$)</th>
<th>WS (m s$^{-1}$)</th>
<th>PNC ($10^3$ cm$^{-3}$)</th>
<th>NO$_x$ (µg m$^{-3}$)</th>
<th>WS (m s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ≤ WD &lt; 45</td>
<td>3.9 ± 3.8</td>
<td>109</td>
<td>14.9</td>
<td>2.2</td>
<td>0.7</td>
<td>109</td>
</tr>
<tr>
<td>45 ≤ WD &lt; 90</td>
<td>6.9 ± 2.4</td>
<td>60</td>
<td>32.0</td>
<td>1.5</td>
<td>0.8</td>
<td>67</td>
</tr>
<tr>
<td>90 ≤ WD &lt; 135</td>
<td>8.0 ± 3.3</td>
<td>63</td>
<td>36.4</td>
<td>1.2</td>
<td>0.7</td>
<td>75</td>
</tr>
<tr>
<td>135 ≤ WD &lt; 180</td>
<td>8.9 ± 3.2</td>
<td>28</td>
<td>48.4</td>
<td>0.7</td>
<td>0.5</td>
<td>30</td>
</tr>
<tr>
<td>180 ≤ WD &lt; 225</td>
<td>8.0 ± 3.9</td>
<td>26</td>
<td>67.6</td>
<td>0.3</td>
<td>0.1</td>
<td>27</td>
</tr>
<tr>
<td>225 ≤ WD &lt; 270</td>
<td>12.6 ± 4.6</td>
<td>8</td>
<td>51.8</td>
<td>0.4</td>
<td>0.2</td>
<td>9</td>
</tr>
<tr>
<td>270 ≤ WD &lt; 315</td>
<td>8.7 ± 4.8</td>
<td>14</td>
<td>35.3</td>
<td>3.1</td>
<td>5.2</td>
<td>14</td>
</tr>
<tr>
<td>315 ≤ WD &lt; 360</td>
<td>5.5 ± 3.7</td>
<td>123</td>
<td>23.3</td>
<td>1.7</td>
<td>0.6</td>
<td>124</td>
</tr>
</tbody>
</table>

Table 5. Particle growth (GR) and formation ($J_{10-25}$) rates during new particle formation events.

<table>
<thead>
<tr>
<th>NPF event days</th>
<th>Growth Rate (nm hr$^{-1}$)</th>
<th>Formation rate ($J_{10-25}$, cm$^{-3}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/18</td>
<td>21.0</td>
<td>&lt; 0.10</td>
</tr>
<tr>
<td>1/20</td>
<td>7.0</td>
<td>0.11</td>
</tr>
<tr>
<td>1/31</td>
<td>12.7</td>
<td>0.16</td>
</tr>
<tr>
<td>Average</td>
<td>13.5 ± 7.0</td>
<td>0.12 ± 0.03</td>
</tr>
</tbody>
</table>
mode particle formation via photochemical production of ambient H$_2$SO$_4$, which was defined by the product of shortwave solar radiation (SSR) and SO$_2$ divided by the condensation sink (CS) of pre-existing particles (SSR × SO$_2$/CS). Fig. 7 illustrates the temporal variations of H$_2$SO$_4$ proxy, particle condensation sink and size distribution during the measurement period. In general, the higher H$_2$SO$_4$ proxy value the higher number concentration of nucleation mode particles measured (Cheung et al., 2013). However, it was noted that the particle number concentration of nucleation mode particles (i.e., N$_{10-25}$) not solely associated with H$_2$SO$_4$ proxy in this study. The averaged H$_2$SO$_4$ proxies during LSB1 and LSB2 were 11.3 × 10$^3$ Wm$^{-2}$ ppb s and 39.0 × 10$^3$ Wm$^{-2}$ ppb s, respectively, while average N$_{10-25}$ for these periods were 1390 cm$^{-3}$ and 490 cm$^{-3}$, respectively. Relatively high H$_2$SO$_4$ proxies observed in the M2 period (during the lockdown) in which only three weak NPF events occurred (i.e., 28 January, 29 January, 30 January), demonstrating that occurrence of NPF in urban Guangzhou is not solely governed by precursors such as sulfuric acid. In addition, we observed that a relatively stronger wind speed was found during the weak NPF event days (i.e., 28 January, 29 January, 30 January, averaged wind speed: 2.2 ± 0.7 m s$^{-1}$) compared to that for strong NPF event days (i.e., 18 January, 20 January and 31 January, averaged wind speed: 1.3 ± 0.7 m s$^{-1}$) (see Fig. 8). In this study, the condensation sink (CS) for different periods were 0.0363 s$^{-1}$ and 0.0143 s$^{-1}$ for M1 and M2, and 0.0416 s$^{-1}$ and 0.0357 s$^{-1}$ for LSB1 and LSB2, respectively. In general, higher condensation sink (CS) was observed during the period before the CNY holiday (i.e., M1 and LSB1) and also higher for Land and Sea Breeze periods than that of Monsoon periods, as more pre-existing particle existed due to more local emissions, which impede the NPF processes. Bousiotis et al. (2021) showed that the wind speed has positive and negative effects on the occurrence of NPF event which varied depending on the air masses and local conditions. High wind speed could enhance the occurrence of NPF event by increased mixing of condensable compounds which eventually lower the condensation sink. On the other hand, the high wind speed may impede NPF due to increased atmospheric dilution (Bousiotis et al., 2021). Our results therefore provide evidence that mix of conditions were affecting the NPF process, where NPF events occurred when the CS level and wind speed are low. This indicated that local conditions need to assess to better understand the NPF process.

Fig. 7. From bottom to top panel. Temporal profiles of (a) Number concentrations of particles ranging from 10–25 nm diameter (N$_{10-25}$), and 25–480 nm diameter (N$_{25-480}$); (b) particle size distribution, geometric mean diameter (GMD); (c) particle condensation sink and H$_2$SO$_4$ proxy with wind speed on color scale. NPF events were highlighted by red rectangular, and weak NPF events were highlighted by blue rectangular.
To investigate the effects of particle size on NPF, the median particle size distributions for NPF event days and non-NPF event days is plotted (see Fig. 9). The PSD data were fitted by multiple log-normal distribution algorithms by DO-FIT model (Hussein et al., 2005). Three modes represented for nucleation, Aitken and accumulation mode particles were identified for NPF and non-NPF days. In general, comparable median total number concentrations were found for NPF ($5.5 \times 10^3$ cm$^{-3}$) and non-NPF ($7.1 \times 10^3$ cm$^{-3}$) event days. The median PNCs for nucleation, Aitken and accumulation modes were $3.2 \times 10^3$, $1.7 \times 10^3$ and $0.6 \times 10^3$ cm$^{-3}$ for NPF event days, and $2.1 \times 10^3$, $3.0 \times 10^3$ and $0.7 \times 10^3$ cm$^{-3}$ for non-NPF event days, respectively. The higher Aitken mode particles were observed during non-NPF event days showing particle during this period was emitted from diesel and petrol engine emissions produce particles in the size range of about 20–130 nm and 20–60 nm, respectively (Morawska et al., 2008). The higher nucleation mode PNCs observed during NPF event days were similar to those reported in other studies (e.g., Cheung et al., 2016) suggesting that new particle formation significantly attributed to the PNC which was dominated by nucleation mode particles.

In addition, a gradually increase of PM$_{2.5}$ was observed followed by the NPF events (see Fig. S1). The peaks of PM$_{2.5}$ were observed about 8–13 hr after the maxima PNCs observed during the NPF events. Kulmala et al. (2021) reported that about 65% of haze particles resulted from NPF, and there is about 1–3 days delay to build up the haze episodes in Beijing, China. The moderate PM$_{2.5}$ levels, ranged from 41–48 µg m$^{-3}$, were observed after the NPF events due to the subsequent growth of newly formed particles in the study region.

4 CONCLUSION

A continuous measurement of particle number concentrations and size distribution was conducted at urban (SYSU) and suburban (Panyu) areas of Guangzhou, South China during 16 January to 3 February 2020 before and during the CNY holiday. The average PNCs were $6.3 \times 10^3$ cm$^{-3}$ and $9.7 \times 10^3$ cm$^{-3}$, respectively for urban and suburban sites. The PNC levels of Guangzhou were significantly influenced by the meteorological conditions and emission activities as exemplified by the lower PNCs during the CNY period which is influenced by the higher atmospheric dispersion due to monsoon circulation, and lower primary emissions during the holiday. Diurnal variations of particle size distribution and PM$_{2.5}$ data obtained in urban Guangzhou explicating the PNCs variations were mostly affected by vehicular emissions in morning and afternoon peak hours, as well as photochemical production at noon time. Smaller particles in the atmosphere tend to
coagulate with larger particles which leads to significant decrease of concentrations of smaller particles ($N_{10.25}$ and $N_{25.100}$). A moderate correlation ($r = 0.60$) obtained between the PNCs of at both the urban and suburban sites which implied that PM pollution was a regional pollution issue for Guangzhou, especially under the influence of monsoon which a significantly higher correlation coefficient ($r = 0.70$) compared to that during land-sea breeze period ($r = 0.30$). The high PNC correlation found in the megacity of Guangzhou evidenced that the particulate matter (PM) pollution occurred at a regional scale, which is impacted significantly by local emission sources (Aitken mode particles) and the NPF process (nucleation mode particles), under the influences of monsoon and land-sea breeze. This indicated that the region is affected by a severe ultrafine particulate pollution. A higher $N_{10.25}/H_2SO_4$ proxy ratio was obtained under lower wind speed condition during NPF events in an urban environment. The significantly higher PNC of nucleation mode particles during NPF events were found to be associated with lower wind speed condition.

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