HOURLY PM2.5 EXTREMES VARIATION IN CONJUNCTION WITH METEOROLOGY IN URBAN HONG KONG

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ABSTRACT: Atmospheric aerosol particles with diameters of less than 2.5 mm (PM2.5) have significant health effects on both human and various ecosystems. With increasing traffic and energy consumption, PM2.5 has become the main type of air pollutant in Hong Kong, and extreme concentrations of PM2.5 appear to occur more frequently. This paper investigates the variations in the extreme hourly PM2.5 concentrations from the Air Pollution Index (API) monitoring station in Central - Hong Kong, which represents a typical urban area of Hong Kong. The hourly PM2.5 concentration exhibits the distinct seasonal and diurnal variations, which were impacted by traffic strength and meteorological conditions. The analysis results reveal that firstly, significant diurnal bimodal pattern of PM2.5 with peaks in morning (8:00-10:00am) and afternoon rush hours (18:00-20:00pm) are noted, lowest concentrations are generally found around noon time (12:00-14:00pm). Secondly, seasonal variations of PM2.5 concentrations with their highest concentration during winter and lowest during summer times, which are driven by seasonal variability in wind directions and temperatures. Thirdly, the pronounced variations are commonly contributed to anthropogenic factors, such as enhanced traffic density, yet meteorological conditions also have some significant influence in Hong Kong.

1. INTRODUCTION

The impact of Atmospheric Particulate Matter (PM) receives more and more attention due to its considerable role in atmospheric processes, thereby affecting air quality, climate change and human health. Environmental epidemiological studies have found PM affects pulmonary function and thereby inducing respiratory diseases and adverse effects on public health and even premature death (Cohen et al., 2005; Kuenzli et al., 2004; Ostro et al., 2008; Peng et al., 2008; Schwartz, 2003; Wilson and Suh, 1997). Particles with an aerodynamic diameter less than 2.5 um (PM2.5) are deeply inhaled and therefore offer a greater impact on public health (Chan and Kwok, 2000).

The transport, presence and formation of PM2.5 is very dependent on the meteorological conditions and source emissions (Elminir, 2005; Wise and Comrie, 2005; Dawson et al., 2007). The behavior of PM2.5 was studied to compare the meteorology (wind speed, wind direction, temperature, humidity, mixing height, precipitation, pressure and cloud cover) of numerous studies worldwide. For instance, Jung et al. (2000) argued that atmospheric transport accounts for high PM2.5 observation in Ohio; high concentrations were particularly detected when the wind speed was lower than 8mph and the temperature was higher than 70ºF. Bari et al. (2003) studied the behavior of PM2.5 records in New York and found that PM2.5 mass has a significant regional component with little influence from local sources; the hourly mean concentrations showed a bimodal pattern. Hien et al. (2002) revealed that the fine particles were governed mainly by wind speed and temperature and 60% to 74% day-to-day variation of particulate concentrations can be explained by meteorological parameters. Relative humidity was highly correlated to fine particulates in winter (Chiang et al., 2005). Li et al. (2005) suggests stable atmospheric conditions with southerly winds are in strong correlation with the recorded high PM2.5 concentration. Guerra et al. (2006) argues that the significant effect of wind direction for PM2.5 in Kansas, with observed high PM2.5 levels on days with predominantly south wand calm winds. Xu et al. (2007) reveals that the change of the concentration of PM2.5 is well related to pressure, relative humidity, and wind speed.

With increases in traffic and energy consumption caused by the dense urbanization, PM2.5 has become the main type of air pollutant in Hong Kong according to a recent report of Hong Kong Environmental Protection Department (HKEPD, 2004). Despite that there do exist some PM2.5 studies in Hong Kong (Cao et al., 2003; Fung et al., 1995; Ho et al., 2003; Louie et al., 2004; Pathak et al., 2003; Qin et al., 1997; So et al., 2007), their main focus however, is the chemical composition. The extensive and comprehensive meteorology contribution to PM2.5 loadings is poorly understood in Hong Kong and only a few studies link pollutants pattern to limited meteorological parameters such as wind effects (Cheng and Lam, 1998).

Understanding the pattern of pollutant and quantifying the relative contribution of different meteorological variables are critical in developing control and mitigation strategies to safeguard public health. Thus a detailed analysis of the pattern of PM2.5 extremes and related meteorology contribution is imperative in Hong Kong. This paper was formulated to test if meteorology played a significant role in affecting the PM2.5 extreme concentrations in urban Hong Kong.

2. SITE DESCRIPTION

Hong Kong is a high dense populated city situated in the sub-tropical climate region with steep mountains and deep sea. Hong Kong's 80% pollutions are from the Pearl River Delta Region due to prevailing winds. Due to the very dense configuration of buildings and the complex terrain bulks, solar energy is stored and heat release and ventilation blocked.

3. DATA

Several datasets on PM2.5 concentrations and corresponding meteorological data were obtained from the monitoring agencies in Hong Kong to analyze and characterize the PM2.5 particle pollution in urban Hong Kong. These data were collocated in both space and time as the basis for statistical analysis. In this study, PM2.5 data recorded by Central station (22°16'54", 114°9'29") (Fig. 1) is dedicated to represent PM2.5 particle pollution over urban Hong Kong. The histogram of hourly PM2.5 concentrations at Central station is shown in Fig. 2. Temperature (TEMP), relative humidity (RH), mean sea level pressure (MSLP), wind direction (WD) and wind speed (WS) were collected from Hong Kong Observation (22°18'07", 114°10'27"), which were applied to represent the meteorological conditions for Central station (Fig. 1), while wind speed and wind direction was collected from Central Pier observation station at (22°17'20", 114°09'21") for representation the wind conditions for Central station as geographical proximity.

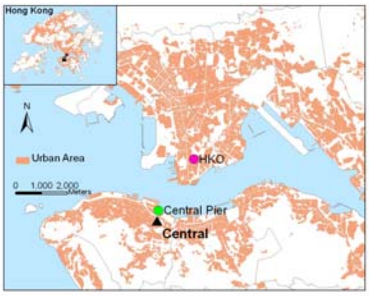


Fig. 1 Location of PM2.5 Central Station, Central Pier and Hong Kong Observatory.

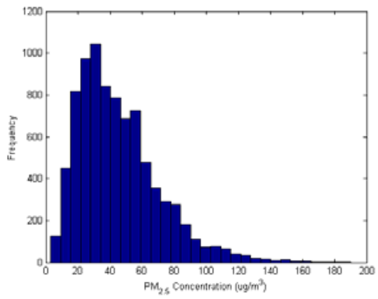


Fig. 2 Distribution of hourly PM2.5 concentrations at Central station.

4. ANALYSIS AND RESULTS

4.1 Seasonal pattern of PM2.5 concentrations

Seasonal patterns of PM2.5 concentrations at Central station are displayed in Fig.3. Concentrations were higher in winter and autumn and lower during spring and summer (Fig. 3). The patterns show that PM2.5 is relative to the meteorological factors. For example, wind direction and temperature show the opposite seasonal pattern, while others factors don't.

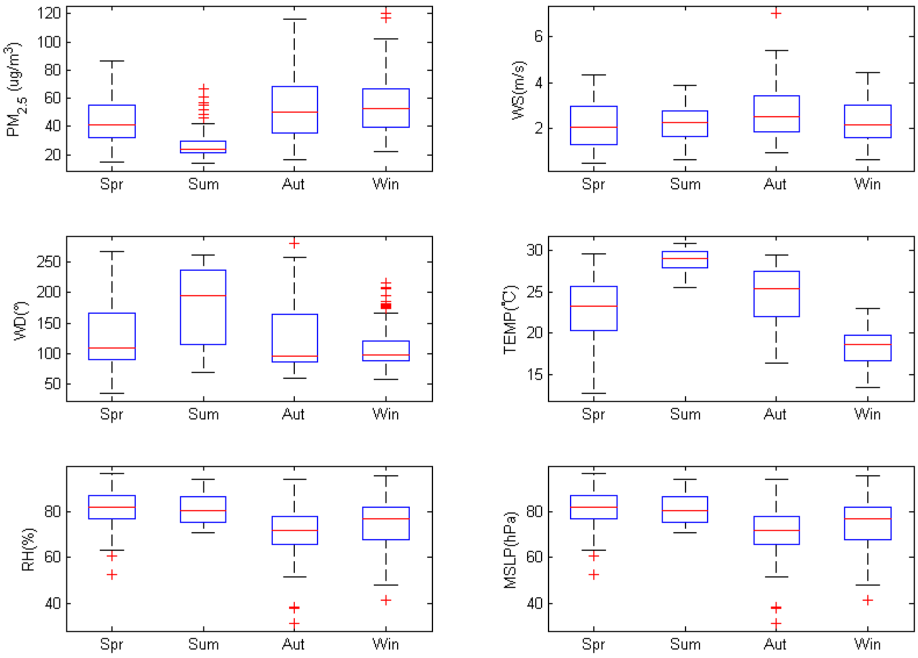


Fig. 3 Seasonal patterns of PM2.5 concentrations at Central Station.

Monthly variations in PM2.5 are obvious. The highest PM2.5 concentrations occurred in December and January (Fig.4), however, the lowest PM2.5 concentrations appeared in June and July. Different from seasonal patterns of PM2.5 concentrations, RH and MSLP are related to PM2.5 concentrations.

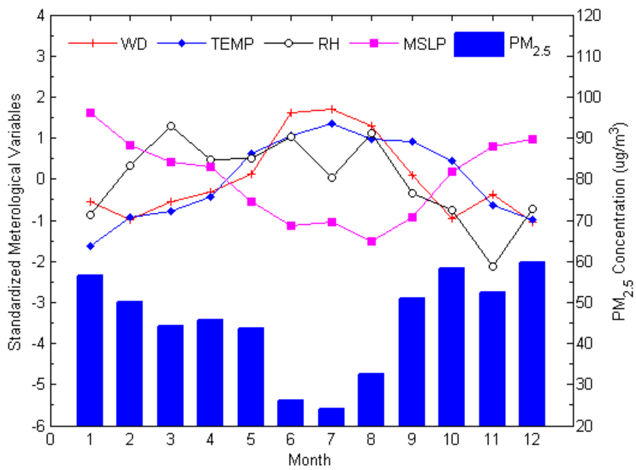


Fig. 4 Monthly patterns of PM2.5 concentrations at Central station.

4.2 Diurnal pattern of PM2.5 concentrations

Diurnal pattern of PM2.5 concentrations exhibited a bimodal pattern (Fig. 5) with an overnight minimum (1:00-5:00am), a relatively low PM2.5 concentration around noon (12:00-14:00pm) and two marked peaks (morning rush hours (8:00-10:00am) and evening rush hours (18:00-20:00pm). The peak values are higher on workdays with more anthropogenic activities (Fig. 5). The concentrations peaks are likely related to a blend of anthropogenic activities and meteorological influences, typically when high traffic density occurs.

Daily MSLP had a similar pattern to that of PM2.5 in despite of time lag, which displayed two clear maxima around 10:00am and 23:00pm. In contrast, TEMP and WS exhibited a unimodal pattern characterized by midday maxima around 13:00pm. Such phenomenon explained the degradation of PM2.5 during noontime with higher temperature and better diffusion. RH, however, exhibited an inverse unimodal pattern with stably overnight maximum values, which suggested the negative association with nocturnal PM2.5 concentrations. A high RH will depress the adsorption of gas phase organic species into particle surface (Pankow et al.,1993) and accelerate the removal of particle by dry deposition, a mechanism enhanced for hygroscopic particle(Zhan et al., 2009). Thus, PM2.5 kept constant minimum values between 2:00 to 5:00 am.

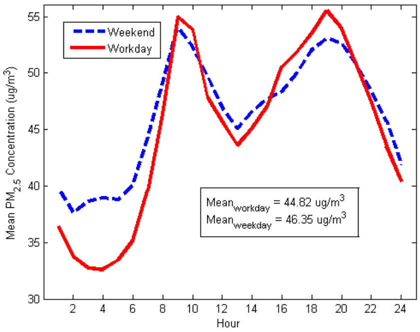


Fig. 5 Diurnal pattern of PM2.5 concentrations.

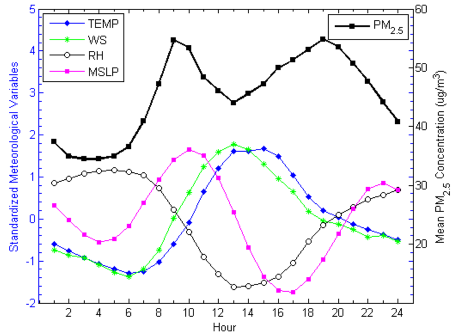
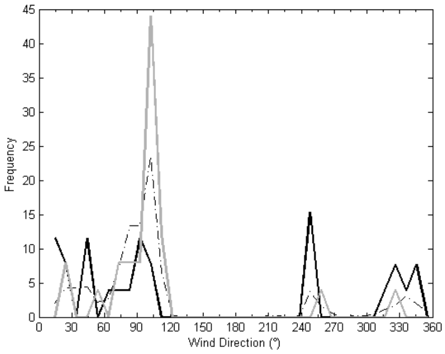


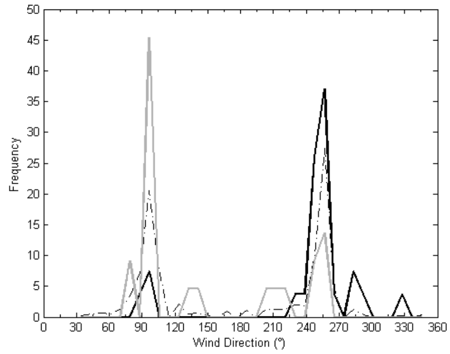
Fig. 6 Diurnal pattern of PM2.5 concentrations in terms of meteorology.

4.3 Pattern of PM2.5 extremes

During the rush hour periods (8:00-10:00am and 18:00-20:00pm), over 40% of the >95 percentile winter PM2.5 concentrations occurs with wind direction between 240° and 270° (Fig. 7b). On the other hand, the accumulation of high summer PM2.5 concentration was favored by wind from mainland (Fig. 7a). Approximately 40% of the higher winter PM2.5 concentrations were registered when wind was blowing from 45°-75° and 315°-345°. Given the difference of wind direction behaviors in winter and summer, lower PM2.5 pollution was found to be highly associated with that the prevailing eastern wind blowing from sea (90°-115°). This suggests the great significance of eastern sea wind in reducing the magnitude of PM2.5.



(a)



(b)

Fig. 7 Frequency of rush hour (8:00-10:00am and 18:00-20:00pm) PM2.5 concentrations above the 95th percentile (thick black) and below the 5th percentile (thick gray) conditional upon the occurrence of wind direction in (a) summer and (b) winter.

In winter, the >95 percentile PM2.5 concentrations occurs with MSLP around 1021 hPa (Fig. 8b), while the distribution of the >95 percentile PM2.5 concentrations is not obvious in summer (Fig. 8a). In summer, the >95 percentile PM2.5 concentrations occur easily with higher RH (Fig. 9a). Contrast to summer, the >95 percentile PM2.5 concentrations occur easily with lower RH in winter (Fig. 9b).

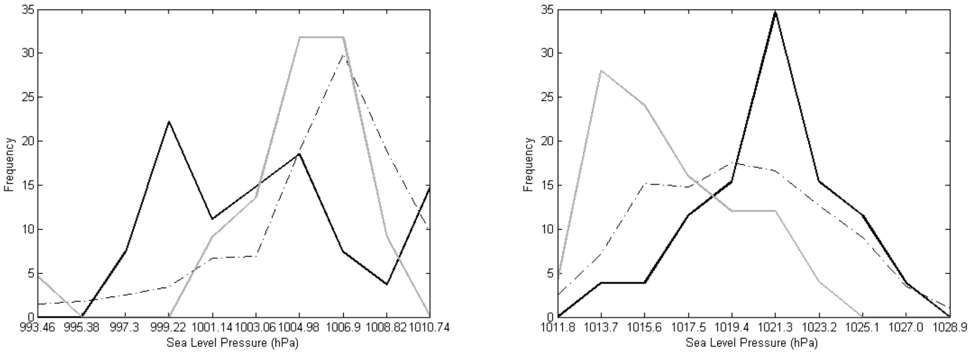


Fig. 8 As in Fig. but for Mean Sea Level Pressure (MSLP).

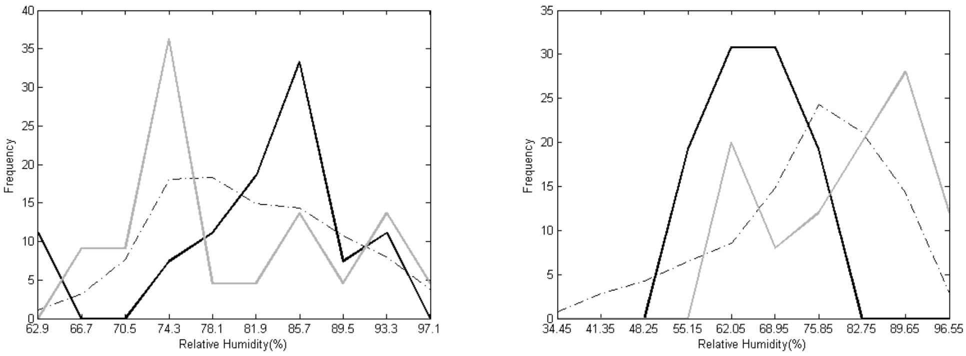


Fig. 9 As in Fig. but for Relative Humidity (RH).

5. CONCLUSION

The temporal patterns of PM2.5 and the seasonal and diurnal significance of meteorological variables affecting the PM2.5 concentrations were studied to understand the behavior of PM2.5 in terms of best sets of weather conditions. In this paper, the exploration of temporal patterns of PM2.5 and meteorological variables was conducted to understand the interaction mechanisms among them physically. Primarily, the hourly-record PM2.5 data exhibits the distinct seasonal and diurnal variations, which were regulated by the traffic strength and the meteorological conditions. The results reveal that pronounced diurnal bimodal pattern of PM2.5 with peaks in morning (8:00-10:00am) and afternoon rush hours (18:00-20:00pm) is attributable to enhanced traffic density and meteorological conditions. Stronger wind and warmer temperature may lead to lower midday concentrations, while the increasing relative humidity brings PM2.5 down to a broad overnight minimum by dry deposition. Significant seasonal variations of PM2.5 concentrations with highest concentration in winter and lowest in summer are driven by seasonal variability in wind direction, precipitation and temperature. The highest summer PM2.5 concentrations (e.g. value≥the 95th percentile) are observed under southwest wind with lower relative humidity.

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