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Characteristics of air pollution in different zones of Sichuan Basin, China

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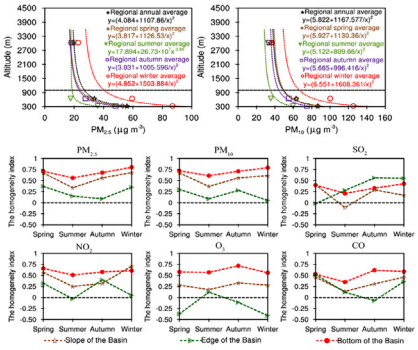
HIGHLIGHTS

- Air pollution was studied in the bottom, slope and edge zone of Sichuan Basin.
- Variations of $PM_{2.5}$ and PM_{10} concentrations with altitude can be fitted by $y = (a + b / x)^2$.
- Horizontal homogeneities of $PM_{2.5}$ and PM_{10} are strong in the bottom of the basin.
- Gaseous pollutant concentrations exhibited diverse variations with altitude.

GRAPHICAL ABSTRACT



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ABSTRACT

Sichuan Basin, located in southwest China, has been ranked as the fourth of heavily air polluted regions in China partly due to its deep mountain-basin topography. However, spatial-temporal distribution of air pollution over the basin is still unclear due to the lack of monitoring data and poor knowledge. Since January 2015, six criteria air pollutants began to be monitored in 20 cities across the basin. The measured data enable us to analyze the basin-wide spatial-temporal distribution characteristics of these air pollutants. Results revealed heavy air pollution in the bottom zone, medium in the slope zone, and light pollution in the edge zone of the Basin in terms of the altitudes of air quality monitoring stations across the Basin. The average concentrations of $PM_{2.5}$ and PM_{10} were 55.87 μg/m^3 and 86.49 μg/m^3 in the bottom, 33.76 μg/m^3 and 63.33 μg/m^3 in the slope, and 19.71 μg/m^3 and 35.06 μg/m^3 in the edge, respectively. In the bottom and slope of the basin, high $PM_{2.5}$ concentration events occurred most frequently in winter. While in summer, ozone became primary pollutant. Among the six air pollutants, concentrations of $PM_{2.5}$ and PM_{10} decrease dramatically with increasing altitude which was fitted by a nonlinear relationship between particulate matter (PM) concentrations and altitude. This relationship was validated by extinction coefficient profiles from CALIPSO observations and EV-lidar data, and hence used to reflect vertical distribution of air PM concentrations. It has been found that the thickness of higher PM concentrations is less than 500 m in the basin. In the bottom of the basin, PM concentrations exhibited stronger horizontal homogeneities as compared with those in the North China Plain and Yangtze River Delta. However, gaseous pollutants seemed not to show clear relationships between their concentrations and altitudes in the basin. Their horizontal homogeneities were less significant compared to PM.

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1. Introduction

With rapid economic development and urbanization acceleration in China, urban air pollution becomes a serious problem due to a significant increase in air pollutant emissions (Brauer et al., 2012; Fang et al., 2009; Li et al., 2017). Although the excessive emission is a key factor to cause heavy air pollution, local complex terrain and meteorological conditions also play a very important role on regional air quality (Deng et al., 2014; Hu et al., 2014; Tao et al., 2014). It has been widely noticed that heavy air pollution events often take place in mountainous (basin) cities (Boznar et al., 1993; Gustin et al., 2015; Jazcilevich et al., 2005; Saide et al., 2011). Heavy air pollutions occurring in many cities of China, such as Taiyuan, Beijing, Hong Kong, and Lanzhou, were significantly affected by mountain-valley topography (He et al., 2015; Miao et al., 2015; Yim et al., 2014; Zhao et al., 2015). Complex terrain and special local meteorological conditions have been also observed to be conducive to worsen regional air quality in the Sichuan Basin which is now ranked as the fourth of heavily polluted regions in China following Beijing-Tianjin-Hebei region, the Yangtze River Delta, and the Pearl River Delta (Zhang et al., 2012). However, the spatial-temporal distribution characteristics of air pollution in the basin are still unclear due to the lack of monitoring data and limited researches.

Sichuan Basin is a large deep basin with 20 cities including two mega cities Chengdu and Chongqing. The Basin is characterized by high population densities, a large amount of motor vehicles, and rapidly developed industrialization. The gross domestic product (GDP) of the 20 cities during 2015 is about 670.1 billion US dollars. Because of the large amount of energy consumption and anthropogenic emissions, the air quality in the basin has been worsening over the past decades (Chen et al., 2014). Under the effects of the particular topography of Sichuan Basin, the air temperature drops slowly in night which causes small temperature gradient between the daytime and nighttime. Low wind speed throughout a year is beneficial to the occurrence of air stagnation (Chen and Xie, 2012; Huang et al., 2017; Wang et al., 2017). Tibetan Plateau and Yunnan-Guizhou Plateau force a unique atmospheric circulation in the Basin (Wang and Tan, 2014; Yu et al., 2016), resulting in high humidity and frequent occurrence of fog which favor the formation and growth of particulate matter (PM) (Luo Yunfeng et al., 2000; Niu et al., 2010). Heavy emissions, particular topography, and unique atmospheric circulation all together cause the heavy wintertime fine particle pollution over the basin (Liao et al., 2017; Tao et al., 2013a) which is now one of the most heavily contaminated regions by $PM_{2.5}$ (Battelle Memorial Institute and Center for International Earth Science Information Network - CIESIN - Columbia University, 2013). In summer, surface ozone becomes primary air pollutant over the Basin.

Fine particles and toxic gaseous pollutants can cause respiratory diseases, cardiovascular diseases, and lung cancer (Guo et al., 2016; Langrish et al., 2012; Pope and Dockery, 2006). Due to heavy air pollution across the Basin, there is an urgent need to investigate the spatial and temporal distribution of air pollutants over the Basin. Previous studies for air pollution were mostly performed in the two megacities Chengdu and Chongqing located in the bottom of the basin (Chen et al., 2017; Li et al., 2015; Zhang et al., 2017) because of sparse measurements in other places of the Basin.

Since January 2015, the real-time hourly concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter with aerodynamic diameter equal to or less than 10 μm (PM_{10}), $PM_{2.5}$, carbon monoxide (CO), 1 h mean ozone (O_3) and 8 h mean O_3 began to be routinely monitored by Chinese Ministry of Environmental Protection (MEP) in 20 cities of the Sichuan Basin. The monitoring program covers all prefecture-level cities of the Basin. These data enable us to examine the changes in sampled air pollutants with altitudes of the Basin and their horizontal homogeneities. The extinction coefficient profiles from CALIPSO observations and the EV-lidar in Chengdu were used to verify the vertical distribution of PM concentrations. The objective of this article is to explore the distribution of air pollution in a three-dimensional space of the Basin and its temporal variation.

2. Methods and data

2.1. Description of study areas and methods

Located in the east of the Tibetan Plateau, the maximum depth of the Sichuan Basin is more than 2000 m. The Basin is surrounded by Daba and Qinling Mountains to the north, Yunnan-Guizhou Plateau to the south, and Wushan Mountains to the east (Fig. 1). Low wind speed and frequent temperature inversion prevail in winter due to Basin's topography forcing (Chen and Xie, 2012; Li et al., 2015; Yu et al., 2016). The unique meteorological conditions in the basin lead air pollution mechanism to be distinctive from other places of China (Chen et al., 2014).

A total of 20 cities in the Basin are selected and categorized into three zones in terms of their respective altitude and terrain characteristics. These are the bottom zone, slope zone, and edge zone. Fifteen cities, Chengdu (CD), Zigong (ZG), Meishan (MS), Luzhou (LZ), Deyang (DY), Neijiang (NJ), Leshan (LS), Dazhou (DZ), Yibin (YB), Nanchong (NC), Ziyang (ZY), Guangan (GA), Suining (SN), Chongqing (CQ) and Mianyang (MY) are located in the bottom zone. Three cities, Yaan (YA), Bazhong (BZ) and Guangyuan (GY) are located in the slope zone. The other two cities Ganzizhou (GZZ) and Abazhou (ABZ) are located in the edge zone. Air pollutions in the three zones are comparatively analyzed to elucidate their characteristics of spatial and temporal distribution.

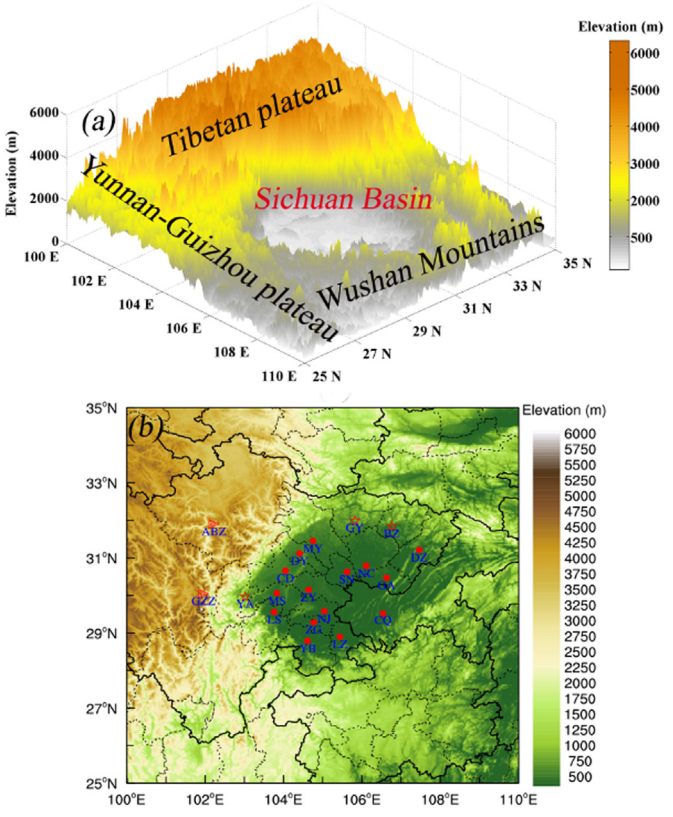

Fig. 1. (a) Three-dimensional terrain in the Sichuan Basin and its surrounding areas; (b) locations of the cities in the basin (the cities in the bottom zone of the Basin are marked with red solid dots, the cities in the slope zone are marked with red five-pointed stars, and the cities in the edge zone are marked with red triangles). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)