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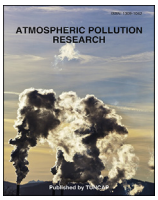

Study of continuous air pollution in winter over Wuhan based on ground-based and satellite observations

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ABSTRACT

A comprehensive research was conducted to analyze the formation and characteristics of continuous air pollution during winter in Wuhan, China, based on ground and satellite joint observation. The effect of meteorological conditions, the source of pollutants and the optical properties of aerosols were investigated. The pressure and the accumulation of pollutants were the two main causes of continuous haze formation. The continuous cold high-pressure system, accompanied by a stable inversion layer, limited the contaminants below the height of 700 m on 15–23 January. The height of the boundary layer was below 1 000 m, based on the lidar observation. Meteorological condition contributes to the accumulation of pollutants. Then, dust transport and local anthropogenic pollutant emissions promoted the accumulation of pollutants, resulting in continuous haze pollution. Different from the heavy pollution (the 24 h-average PM2.5 is more than 200.0 μgm^{-3}) over the Beijing-Tianjin-Hebei region, the contaminants in the Wuhan area were mainly primary pollutants, including airborne dust and anthropogenic pollutants. Moreover, a photochemical reaction was observed. However, the extent of secondary pollution formation was not high during haze pollution. Result in the particle size distribution confirmed the process of dust transport. Fine-mode and coarse-mode particles sometimes appear in the haze pollution in winter. According to the satellite data, the AOD maintained a large level of approximately 0.8 during the pollution. The aerosol extinction ability was relatively strong during the pollution period, whether aerosol is absorbed or a scattering effect dominated. In this study, the formation process of haze pollution revealed which can be used to validate air-quality models over the Wuhan region and can also provide guidance for government for the prevention work of haze pollution over Central China.

1. Introduction

Anthropogenic emissions have a dramatic increase because of rapid economic development and improvement of living standards over China in recent years (Ma et al., 2010; Li et al., 2011; Zhang et al., 2012). The large amount of anthropogenic emissions has caused great changes in atmospheric air quality and regional climate (Sun et al., 2013). Photochemical pollution and fog-haze frequently occur on densely populated eastern cities (Sun et al., 2006; Meng et al., 2010). Moreover, dust pollution, which is transported from the deserts in northwestern China, is observed during spring and winter (Li et al., 2010). Heavy air pollution has a significant influence on public health (Tie et al., 2009; Miller et al., 2007), radiative forcing and the climate model (Ramanathan et al., 2001). Therefore, the characteristics of air pollution are needed to reveal its the sources, compositions, and chemical characteristics.

A number of studies on the sources, compositions, and formation process of urban air pollution over China have been analyzed. Liu et al. (2013) emphasized that stable weather conditions would be conducive in the accumulation of anthropogenic pollutants, resulting in heavy regional pollution. Li et al. (2013) found that the effect of aerosol transmission is observed among various city clusters during the regional haze pollution in spring over East China. Huang et al. (2010) studied that the natural dust particles from the deserts in northwestern China could be transported to

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eastern China. Meanwhile, Zhao et al. (2013) indicated that secondary pollutant processes could generate large amounts of secondary pollutants during heavy pollution. Moreover, Wang et al. (2006) studied the different chemical characteristics of aerosols under different weather conditions in Beijing and found that sulfates and nitrates were the dominant fractions during dust and haze pollution in the spring season. Moreover, Tao et al. (2014) emphasized that the haze pollution area was covered by haze clouds, which has no significant direct contribution to the heavy urban pollution. Some studies investigated the case study over central China, especially during extreme weather. Tao et al. (2013) analyzed the formation of abnormal yellow pollution during the summer agricultural burning season. Zhang et al. (2014) studied the characteristics of optical aerosol during severe haze pollution on ground-based and satellite data. However, studies about the formation and characteristics of haze pollution in the Wuhan area thus far are few. Different from the Beijing-Tianjin-Hebei region, Wuhan is located in the central China region, without large industrial emissions and heavy air pollution. However, moderate haze events occurred frequently. The environmental problems over the Wuhan area have attracted increasing attention because of the development of central China. Moreover, long-term exposure to air pollution would have a great harm to human health. Furthermore, comprehensive understanding of the source, characteristics and formation process of pollution is significant to protect human health and to improve regional chemistry and climate models.

A comprehensive research was conducted on the sources and formation of haze pollution on the Wuhan area, which is located in central China, from January 15–23, 2015 based on the combination of ground with satellite observations. First, the effect of meteorological conditions including relative humidity, temperature, wind speed and pressure on the haze pollution in the Wuhan area was analyzed in detail based on ground observation. Second, the sources of haze pollution were discussed according to the backward trajectories and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) data. Moreover, the ground-based lidar data were used to explain the accumulation of pollutants. Lastly, the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data and sun-photometer data were used to verify the characteristics of haze pollution during winter.

2. Stations and data

Wuhan, as a major industrial city in central China, has a dense population and a good natural environment. However, the environment of Wuhan area has been greatly affected because of the development of central China and the frequent large-scale haze pollution events in recent years (Liu et al., 2017). Fig. 2 shows the MODIS true-color image during the continuous pollution period from the 15 to 23 Jan 2015. The ground was covered by the haze pollution during the aforementioned period. Long-term exposure to this environment, would not only great harm to human health, but also destroy the natural environment. Therefore, a comprehensive study was conducted to study the formation and characteristics of haze pollution.

2.1. Ground-based data

A Mie-lidar system was used to obtain the aerosol vertical extinction coefficient profile. The Mie-lidar system was locked at the roof of State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing (LIESMARS) (114°21′E, 30°32′N), as shown in Fig. 1 (Wei et al., 2015). The laser emits a beam of 532 nm wavelengths, with 150 mJ pulse energy and 20 Hz repetition rate. The vertical resolution of the lidar was 3.75 m, and the temporal resolution was 1 min. The aerosol backscatter signal was received by an optical system and was measured using a photomultiplier tube. The vertical profiles of aerosol backscatter and extinction coefficient were calculated by using the Klett–Fernald method (Fernald, 1984; Klett, 1981). The lidar ratio was 50sr based on the previous study (Wei et al., 2015).

The automatic sun-photometer CE-318 manufactured by Cimel is a high-precision field sun and sky radiation measuring instruments, that is also located on the roof of the LIESMARS station too (Wang et al., 2015). The distance between the sun-photometer and the Mie-lidar is approximately 20 m. It could be used to obtain the volume size distribution of particle and the single scattering albedo (SSA) (Dubovik et al., 2000; Che et al., 2009). The volume size distribution of aerosol in the Wuhan area was analyzed based on the observations on January 2015.

Hourly meteorological data were obtained using an automatic meteorological station located adjacent to the sun-photometer. The distance between the automatic meteorological station and the Mie-lidar is approximately 5 m. Meteorological parameters include wind direction, wind speed, relative humidity (RH), temperature and pressure.

The radiosonde data used in this study were derived from the launches at Wuhan at 8:00 local time (LT) during the study period and were provided by the Bureau of Meteorology (http://data.cma.cn) at 30.37'N, 114.08'E, 23 m above sea level, 30 km northwest from the lidar site. The data were used to study the vertical profiles of temperature during the haze pollution. The concentrations of PM2.5 and gaseous pollutants were also provided by the Bureau of Meteorology (http://data.cma.cn).

The Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model (Stein et al., 2015; Rolph, 2016) of the National Oceanic and Atmospheric Administration (NOAA) was used to calculate backward trajectories to identify the source of polluted aerosol.

2.2. Satellite observations

MODIS is an important sensor mounted on Terra and Aqua satellites. Terra is a morning satellite, and Aqua is an afternoon satellite. Collection 5.1 data with retrieval errors within ±30% were used to analyze the formation process of regional haze pollution (Levy et al., 2010; Hsu et al., 2006). The data on deep-blue aerosol optical depth (AOD) at 550 nm data from MODIS was used to study the haze pollution in central China on January 2015.

CALIPSO satellite provides the global observations data of aerosol and cloud layers to study the effect of clouds and aerosols in the climate change on Earth (Liu et al., 2008). CALIPSO V3.30 data have been corrected and calibrated. The CALIPSO satellite could detect vertical aerosols extinction profiles, and aerosol subtypes including smoke, dust, polluted dust (dust and smoke), clean and polluted continent, and clean marine (Omar et al., 2009). The information of aerosols extinction profiles and aerosol category were used to study the formation process of regional pollution.

3. Results and discussion

First, the pollution time and the main pollutants changes were investigated according to the concentration of pollutants. Then, the effect of meteorological conditions and the source of pollutants were analyzed during the pollution period. Finally, the optical properties of aerosols were studied during the pollution period. Specific analysis is as follows.

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