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Observations of atmospheric pollutants at Lhasa during 2014–2015: Pollution status and the influence of meteorological factors

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ABSTRACT

Atmospheric pollutants including SO_2, NO_2, CO, O_3 and inhalable particulate matter ($PM_{2.5}$ and PM_{10}) were monitored continuously from March 2014 to February 2015 to investigate characteristics of air pollution at Lhasa, Tibetan Plateau. Species exhibited similar seasonal variations except O_3, with the peaks in winter but low valleys in summer. The maximum O_3 concentration was observed in spring, followed by summer, autumn, and winter. The positive correlation between O_3 and PM_{10} in spring indicated similar sources of them, and was assumed to be turbulent transport. Temperature was the dominant meteorological factor for most species in spring. High temperature accelerates O_3 photochemistry, and favors air disturbance which is conductive to dust resuspension in spring. Relative humidity (RH) and atmospheric pressure were the main meteorological factors in summer. RH showed negative correlations with species, while atmospheric pressure posed opposite situation. Wind speed (WS) was the dominant meteorological factor in autumn, the negative correlations between WS and species indicated diffusion by wind. Most species showed non-significant correlations with meteorological factors in winter, indicating the dependence of pollution on source emission rather than restriction by meteorology. Pollution weather character indicated that emissions were from biomass burning and dust suspension, and meteorological factors also played an important role. Air stream injection from the stratosphere was observed during O_3 pollution period. Air parcels from Southwest Asia were observed during air pollution period in winter. An enhancement in air pollutants such as O_3 would be expected in the future, more attention should be given to countermeasures for prevention of air pollution in the future.

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Introduction

Tibetan Plateau (TP) is the highest (average altitude of 4000 m above sea level) and one of the most remote plateaus on the world (Shao et al., 2016; Yang et al., 2013), with an area of approximately 2.5 × 10^6 km^2 and size of about one quarter of the Chinese territory, which extends over the area of 27°–45°N, 70°–105°E (Bu et al., 2015). It is an important ecological security barrier for China and even for the whole of Asia (Loewen et al., 2007), which has long been identified to be critical in regulating the Asian hydrological cycle and monsoon climate (Yanai et al., 1992; Wu and Zhang, 1998; Xu and Chan, 2001). Due to the unique landform, fragile ecosystem, and special monsoon circulation (Qiu, 2008), TP has been regarded as a sensitive region to anthropogenic impact.

Due to the sparse human population and almost no industry (Zhu et al., 2013), TP is often presumed to be a pristine region. It is located at the juncture of several important natural and anthropogenic aerosol sources. Although it is surrounded by the earth's highest mountains, anthropogenic emissions from strong pollution events can occasionally be transported to the central TP by prevailing southwesterly winds (Xia et al., 2011). The high altitudes of the Himalayas block most of black carbon (BC) particles intruding into the TP, but the Yarlung Tsangpo River valley serves as a "leak" by which contaminants can reach the southeast TP (Cao et al., 2010). Taklamakan and Gobi deserts are two major dust sources with long-range transport occurs mainly in spring (Liu et al., 2008). Research (Chan et al., 2006) showed that pollution from active fire regions in southern and western Asia had rather strong impact on the abundance of ozone (O_3), trace gases and aerosols in the background atmosphere of TP. Relative high contents of human harmful trace metals were found in some environmental matrices and large rivers of the TP area (Yang et al., 2007; Zhang, Pan, et al., 2014; Zhang, Sun, et al., 2014; Zhang et al., 2002; Fu et al., 2008; Huang et al., 2008). Trace elements related to anthropogenic activities in snow and ice cores from TP and its surrounding area, such as eastern Tien Shan, Mt. Muztagh Ata in the eastern Pamirs (Li et al., 2006), and Mt. Qomolangma (Everest) in the Himalayas (Kang et al., 2007; Lee et al., 2008; Hong et al., 2009; Kaspari et al., 2009) have been elucidated in several studies. Researches showed that pollutants such as persistent organic pollutants and heavy metals from South and Central Asia could be carried into the TP region through long-range transport by the atmospheric circulation (Huang et al., 2007; Loewen et al., 2007; Wu et al., 2009; Wang, Gong, Yao et al., 2010a; Wang, Gong, Zhang et al., 2010). Dusts and BC from smoke of nearby Southeast Asian countries and the northern part of the Indian Peninsula (Engling et al., 2011) were significantly built-up in TP. Lu et al. pointed out that the contribution of BC from South Asia may account for 67% of BC transported to the Himalayas and the TP region (HTP) on an annual basis (Lu et al., 2012). Research found that the highly elevated surface air over the Plateau may act as an "elevated heat pump" and alter the regional climate significantly through the absorption of solar radiation by dust coupled with black carbon (Lau et al., 2006).

Lhasa is the metropolis of the Tibet autonomous region of China, which is located in the middle of TP. It is a famous city for tourism, and an area with the highest population density and the most concentrated human activities of the Tibet autonomous region. At a high altitude above 3650 m, the absolute content of oxygen in Lhasa is about 68% of that at the sea level (Ran et al., 2014). Much different from other cities in Middle or Eastern China, Lhasa, with a history of limited energy consumption and religious activities such as the burning of juniper, has special atmospheric environment which is much different from other cities on the world (Li et al., 2008; Tao et al., 2010). Furthermore, due to being the largest city of the southern TP, it was suggested that pollutant emissions of Lhasa is a potential pollution source of the south TP (Yu et al., 2001; Zhang et al., 2001). Investigations on surface trace gases have rarely been reported for Lhasa (Yu et al., 2001; Zhou et al., 2001; Tang et al., 2001; Dechen et al., 2008). Although the previous researches have indicated that the air quality in Lhasa was quite fine in comparison with many other cities in China (He et al., 2002), Lhasa occasionally suffered from air pollution due to incomplete fuel combustion in the low oxygen-containing atmosphere (Chaffin and Ullman, 1994; Bishop et al., 2001; Nagpure et al., 2011), as well the increasing motor vehicles and rapid development of tourism resulted in an increase of local atmospheric pollution (Huang, 2001; Zhang et al., 2003). Atmospheric pollutants reduce the visibility, degrade the air quality, and do harm to human health. Particles, such as inhalable particulate matter ($PM_{2.5}$), are of growing concern due to their deeper penetration abilities into lung areas and more adverse health outcomes (Guo, 2015). Previous studies about trace elements of inhalable particulate matter (PM_{10}) in Lhasa reported that the mean elemental concentrations were generally comparable with other European urban areas while much lower than some Asian cities (Cong et al., 2011). The sources of carbonaceous aerosols include emissions from motor vehicles, biomass burning and religious activities of local residents, as well as emissions from ground vegetation and plant residues in soil (Huang et al., 2010; Yu et al., 2001).

In this research, systematically collected data of surface nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide CO, ozone (O_3), and $PM_{2.5}$ and PM_{10} during one year were presented and analyzed in the detail. The seasonal variations of the air pollutants and meteorological factors were discussed in the paper as well. Typical pollution weather and possible emission sources were analyzed; backward trajectories were used to trace the influence of long-distance air flow transportation. The results herein will serve to understand the air pollution characteristics of Lhasa city and provide some suggestions for the mitigation of atmospheric pollutants.

1. Measurement description

Six monitoring sites were located in environmental protection agency of Tibet autonomous region (A), Lhasa railway station (B), Barkhor Street (C), East Jiangsu Road (D), radiation station of Doilungdêqên county (E), and former site of environmental protection bureau which is located across the Niangre road (F). The measurement of O_3, SO_2, CO, and NO_2, along with $PM_{2.5}$ and PM_{10} was conducted from 1st March 2014 to 28th February 2015 in Lhasa. O_3 was measured by a UV photometric analyzer (Thermo 49i, Thermo Fisher, USA), which uses a system on the