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Morphologies and elemental compositions of local biomass burning particles at urban and glacier sites in southeastern Tibetan Plateau: Results from an expedition in 2010

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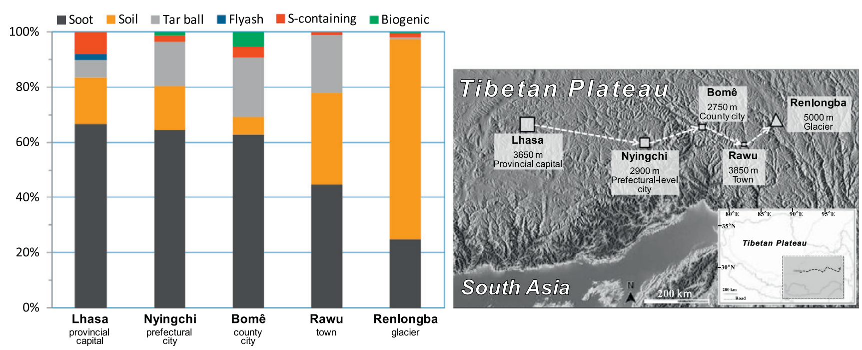
HIGHLIGHTS

- Aerosol particles at urban and glacier sites in southeastern Tibet were analysed.
- Soot aggregates at the glacier site were from biomass burning in the plateau.
- Physically or chemically processed ageing of the aggregates were rarely confirmed.
- Locally-emitted soot may affect glaciers differently than those from South Asia.

GRAPHICAL ABSTRACT



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ABSTRACT

Many studies indicate that the atmospheric environment over the southern part of the Tibetan Plateau is influenced by aged biomass burning particles that are transported over long distances from South Asia. However, our knowledge of the particles emitted locally (within the plateau region) is poor. We collected aerosol particles at four urban sites and one remote glacier site during a scientific expedition to the southeastern Tibetan Plateau in spring 2010. Weather and backward trajectory analyses indicated that the particles we collected were more likely dominated by particles emitted within the plateau. The particles were examined using an electron microscope and identified according to their sizes, shapes and elemental compositions. At three urban sites where the anthropogenic particles were produced mainly by the burning of firewood, soot aggregates were in the majority and made up >40% of the particles by number. At Lhasa, the largest city on the Tibetan Plateau, tar balls and mineral particles were also frequently observed because of the use of coal and natural gas, in addition to biofuel. In contrast, at the glacier site, large numbers of chain-like soot aggregates (~25% by number) were noted. The morphologies of these aggregates were similar to those of freshly emitted ones at the urban sites; moreover, physically or chemically processed ageing was rarely confirmed. These limited observations suggest that the biomass burning particles age slowly in the cold, dry plateau air. Anthropogenic particles emitted locally within the elevated plateau region may thus affect the environment within glaciated areas in Tibet differently than anthropogenic particles transported from South Asia.

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1. Introduction

Atmospheric aerosols derived from natural and anthropogenic emission sources exert an important influence on regional and global climate change both directly, via the scattering and absorption of atmospheric radiation, and through acting as condensation nuclei in the formation of cloud droplets (Buseck and Pósfai, 1999; Kaufman et al., 2002; Akimoto, 2003). In remote glacier areas, the deposition of light-absorbing aerosol components on snow and ice reduces the albedo of these bright surfaces because the dark aerosols enhance the absorption of solar radiation; thus, this deposition accelerates the melting of glaciers and sea ice (Hansen and Nazarenko, 2004; Ramanathan and Feng, 2009; B. Xu et al., 2009; Kopacz et al., 2011; Y. Li et al., 2016; X. Li et al., 2017).

The Himalayas and the Tibetan Plateau are often referred as Earth's "Third Pole" because they contain the world's largest volume of persistent ice outside the Arctic and Antarctica. This area is also called the "Water Tower of Asia" because it contains the headwater areas of several of the major rivers of Asia. The Tibetan Plateau is a high-elevation region in Central Asia. Its average elevation exceeds 4000 m a.s.l., and its area exceeds 2.5 million km^2. Because of the low density of the air and the strong surface heating within this region, dry thermal updrafts trigger deep convection over the plateau and drive the Asian monsoon system; these processes lead to the large-scale convergence of air masses from the surrounding areas, including South Asia (Yanai et al., 1992; Liu and Yin, 2002; Lau et al., 2006). Recent observations and model studies suggest that this region is a key element of the energy cycle that makes up part of the Earth's climate system, owing to the role of this area in the large-scale circulation patterns that connect the Indian Ocean, the Asian continent and the northwestern Pacific (Zhang et al., 2001; Lau et al., 2006; B.Q. Xu et al., 2009; Kang et al., 2010; Lau et al., 2010).

Substantial evidence that the Himalayas and the Tibetan Plateau are constantly exposed to polluted air masses sourced from regions outside of the plateau, including South Asia, central Asia and East Asia, has been provided by studies based on chemical characterizations, satellite observations and numerical simulations (Loewen et al., 2007; Cao et al., 2010; Kopacz et al., 2011; Xia et al., 2011; Lu et al., 2012; S. Zhao et al., 2013; Z. Zhao et al., 2013; Cong et al., 2015; Kang et al., 2016; Lüthi et al., 2015; Fan et al., 2016; Zhu et al., 2016, 2017). Bulk analyses of chemical components (carbonaceous species, water-soluble inorganic ions, and major elements), including in situ measurements of black carbon, and filter-based measurements of elemental carbon and soot have also been carried out on the particulate matter in the plateau air (Cao et al., 2010; Engling et al., 2011; Zhang et al., 2012; Z. Zhao et al., 2013). These studies indicate that air pollutants from Bangladesh and eastern and northeastern India may travel along Himalayan valleys under certain meteorological conditions, thus reaching the southeastern part of the Tibetan Plateau; this movement of polluted air masses is called the "direct channel" (Bonasoni et al., 2010) or "leaking wall" (Cao et al., 2010) behaviour. However, a few recent studies, which have been conducted mainly in the central portion of the Tibetan Plateau and along the western Himalayas, have noted the possible significance of aerosol sources on the plateau (Li et al., 2008; Chen et al., 2015; C. Li et al., 2016; H. Li et al., 2017; Zhang et al., 2017). Unfortunately, very limited data are available on the physical and chemical properties of aerosol particles generated locally or regionally on the plateau. This lack of data is especially pronounced in the regions north of the eastern Himalayas, i.e., the southeastern part of the Tibetan Plateau, and it hinders additional and more detailed studies on the influence of locally emitted anthropogenic particles on the atmospheric and cryospheric environment.

For this study, aerosol particles were collected at four urban sites and one remote glacier site in the southeastern Tibetan Plateau during a scientific expedition. The morphologies of individual particles and their size distributions were determined using a scanning electron microscope. The elements contained in the particles were identified with an energy dispersive X-ray spectrometer attached to the electron microscope (SEM/EDX). Here, the origin and the ageing of the particles are discussed, focusing on the particles at the glacier site.

2. Methodology

2.1. Sample collection

The sample collection was carried out during a scientific expedition that extended from 12 to 18 April 2010 and was conducted along the G318 highway, the longest national highway in China, which passes through the southeastern portion of the Tibetan Plateau. The sampling sites included four urban sites at Lhasa, Nyingchi, Bomê and Rawu, and one glacier site at the remote Renlongba Glacier (Fig. 1).

Lhasa, the administrative capital of the Tibet Autonomous Region, is the biggest city on the plateau, and it has an urban population of approximately 200,000. Lhasa lies in the centre of the plateau, and its elevation is 3650 m. The highest mountain in the area surrounding Lhasa has an elevation of approximately 5500 m a.s.l. Sources of air pollutants in Lhasa include limited industrial facilities; the consumption of biofuel (dried yak dung) for household energy; the burning of coal, natural gas, and liquefied petroleum gas; and the burning of incense for religious activities. Nyingchi, which is also known as Linzhi, is a prefecture-level city located in the southeastern portion of the plateau. Its urban population is approximately 35,000. The city is surrounded by large forests, and the major energy source is firewood. Bomê, also known as Bome, is an agricultural county in Nyingchi Prefecture. Its urban population is approximately 8900 and it is surrounded by forests and mountains. Rawu, also known as Ranwu, is a small town in Baxoi county with a population of <2900. Similar to Nyingchi, the primary energy source in Bomê and Rawu is firewood. Renlongba Glacier is located in an uninhabited area approximately 60 km east of Rawu and 50 km from the G318 highway. The weather during the expedition was fine, and sunny conditions occurred on all of the days on which samples were collected.

The Tibet Autonomous Region contains 5 prefecture-level cities, including Lhasa and Nyingchi; 73 county-level cities, including Bomê; and 694 township-level towns, including Rawu (Yearbook, 2016). Domestic biomass burning is the primary source of energy in the region as a whole, and it accounted for nearly 70% of the energy produced in this region in 2003. Animal waste, firewood, and straw made up 53%, 37%, and 10% of the biomass burned, respectively (Yang et al., 2008; Wang, 2009). With respect to the potential availability of energy, forestry residues are abundant in Tibet, but agricultural residues are rare (Liu and Shen, 2007; Gao et al., 2016). >90% of the forests in Tibet are widely distributed on the southeastern Tibetan Plateau and the northern slope of the Himalayas (Peng et al., 2012; Zhang et al., 2013). Firewood serves nearly all heating and cooking needs in the region (Wei et al., 2004). Animal waste, i.e., yak dung, is the predominant energy source in the pastoral and agro-pastoral regions of the central Tibetan Plateau, including Lhasa (Wang, 2009; Chen et al., 2015). Two of the five prefecture-level cities in central Tibet, including Lhasa, display similar energy consumption structures, and the energy consumption structures of the other three cities in eastern and southeastern Tibet, including Nyingchi, are similar.

At each site, a mini-volume portable sampler (Airmetrics, Eugene, OR, USA) was used to collect the suspended particles and to deposit them onto 47-mm polycarbonate filters (Nuclepore, Whatman International Ltd., Maidstone, UK) with 0.2-μm pores. The operating flow rate of the sampler was 5 L min^{-1}. At the four urban sites, sampling activities were carried out on the roofs of hotels (approximately 5–15 m above ground level) for 3 h each. These sampling sites were surrounded by residences and roads. At the glacier site, the sampler was placed 1.5 m above the ground, and the sampling time was 5 h. After sampling, the filters were sealed in plastic cassettes and stored in a refrigerator at 4 °C until analysis. Air temperature and relative humidity were