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Black carbon aerosol characterization in a remote area of Qinghai–Tibetan Plateau, western China

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HIGHLIGHTS

- Atmosphere over northeast Tibetan Plateau is not pristine, with an average rBC mass concentration of 0.36 μg STP-m^{-3}.
- About 50% of the observed rBC aerosol particles are thickly coated by non-BC materials.
- Non-BC aerosol species affect the Aethalometer measurements at Qinghai Lake.

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ABSTRACT

The concentrations, size distributions, and mixing states of refractory black carbon (rBC) aerosols were measured with a ground-based Single Particle Soot Photometer (SP2), and aerosol absorption was measured with an Aethalometer at Qinghai Lake (QHL), a rural area in the Northeastern Tibetan Plateau of China in October 2011. The area was not pristine, with an average rBC mass concentration of 0.36 μg STP-m^{-3} during the two-week campaign period. The rBC concentration peaked at night and reached the minimal in the afternoon. This diurnal cycle of concentration is negatively correlated with the mixed layer depth and ventilation. When air masses from the west of QHL were sampled in late afternoon to early evening, the average rBC concentration of 0.21 μg STP-m^{-3} was observed, representing the rBC level in a larger Tibetan Plateau region because of the highest mixed layer depth. A lognormal primary mode with mass median diameter (MMD) of ~175 nm, and a small secondary lognormal mode with MMD of 470–500 nm of rBC were observed. Relative reduction in the secondary mode during a snow event supports recent work that suggested size dependent removal of rBC by precipitation. About 50% of the observed rBC cores were identified as thickly coated by non-BC material. A comparison of the Aethalometer and SP2 measurements suggests that non-BC species significantly affect the Aethalometer measurements in this region. A scaling factor for the Aethalometer data at a wavelength of 880 nm is therefore calculated based on the measurements, which may be used to correct other Aethalometer datasets collected in this region for a more accurate estimate of the rBC loading. The results present here significantly improve our understanding of the characteristics of rBC aerosol in the less studied Tibetan Plateau region and further highlight the size dependent removal of BC via precipitation.

1. Introduction

Black carbon (BC), a byproduct of incomplete combustion, is the most efficiently light-absorbing aerosol component in the atmosphere. BC plays a major role in climate change (IPCC, 2007) and has been identified as the second largest contributor to anthropogenic radiative forcing (Jacobson, 2001). Due to its non-uniform spatial and temporal distribution, BC can induce significantly higher regional forcing than CO_2 and methane (Chung et al., 2005, 2010). BC's global, direct, anthropogenic radiative forcing is estimated to be ~0.71 W m^{-2} in 2005 (Bond et al., 2013), while regional surface forcing in northern India, for example, can reach as high as 62 W m^{-2} (Tripathi et al., 2005).

The radiative properties of BC, and hence its climate-related impacts, strongly depend on its mixing state. The internal mixture of BC with

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other particulate matter can enhance the absorption of solar radiation by a factor of about 1.5–2.0 compared to externally mixed BC (Bond et al., 2006; Schnaiter et al., 2005). The mixing state of freshly emitted BC depends on combustion conditions. As the emission plume ages, BC becomes internally mixed through a variety of mechanisms including condensation of emitted semi volatile organic compounds and products from photochemical oxidation (Oshima et al., 2009; Petters et al., 2006).

In addition, the impact of BC on the radiation budget may lead to additional consequences, such as global dimming (Wild et al., 2007), decreased crop yields (Chameides et al., 1999), and negative impacts on terrestrial and aquatic ecosystems (Forbes et al., 2006). Further, BC is also associated with adverse impacts on human health (Pope and Dockery, 2006).

Asia has been identified as a region where large amounts of BC are emitted. However, previous studies on BC focused mainly on rural and urban China (e.g., Cao et al., 2007; Han et al., 2008). Here, we concern BC in the Tibetan Plateau (a remote region of China) where studies of BC are very scarce to date and have applied filter-based techniques that measure bulk aerosol absorption rather than specific BC mass concentration (e.g., Cao et al., 2009a, 2010; Engling et al., 2011). Due to the systematic limitations of most of the current filter-based BC measurements (Bond et al., 2013), direct examination of the BC size distribution and mixing state is not feasible.

Here we report measurements of the refractory black carbon (rBC) mass content of individual aerosol particles at the shore of Qinghai Lake in the Tibetan Plateau region detected with a Single Particle Soot Photometer (SP2) instrument. The rBC content measured by the SP2 corresponds closely (Kondo et al., 2011a) to BC as defined in Bond et al. (2013). The SP2 provides rBC mass concentrations, size distributions, and mixing states based on individually detected particles (Schwarz et al., 2006). The high selectivity of the SP2 response to rBC mass ensures that other light-absorbing species do not contribute to the rBC quantification. Further, an Aethalometer, a filter based instrument, was used to measure the total fine-mode aerosol absorption.

Qinghai Lake (QHL), the largest lake in China, is located 3200 m above the sea level in a drainage basin on the Northeast Tibetan Plateau (Fig. 1). Its size and location (i.e. at the junction point of three major climate systems: the East Asian monsoon, the Indian monsoon, and the Westerly) make it very sensitive to climate changes (An et al., 2012). The ecological status of QHL has attracted great attention worldwide (Lister et al., 1991; Jin et al., 2010). The primary objectives of the QHL study were i) to quantify rBC mass concentrations, size distributions, and mixing states in the region at the season of the measurements, and ii) to derive a suitable scaling factor for Aethalometer measurements in this region/season by comparing simultaneous measurements of SP2 and Aethalometer.

2. Methodology

2.1. Research site

Measurements were taken from 16 to 27 October, 2011 from the rooftop (~15 m above ground level) of a sampling tower at the "Bird Island" peninsula (36.98°N, 99.88°E, 3200 m AMSL), which is located at the northwest section of the QHL shore as shown in Fig. 1. There are four counties around QHL (Fig. 1), including Gangcha, Haiyan, Gonhe, and Tianjun, with a total population of ~230,000. Urban areas are located ~180 km to the southeast of QHL. Although it is a remote region, the traffic flow (in particular diesel vehicles) in the QHL basin is significant because of a national highway surrounding the lake. Biofuels including yak and sheep dung, firewood, and crop residues are the main energy sources in the rural areas of Qinghai, and account for ~80% of total household energy, of which ~65% is from burning of and sheep dung (Ping et al., 2011). Trash burning is also customary in the region.

2.2. Instrument description

The operating principles of the SP2 have been described in detail elsewhere (Schwarz et al., 2006; Gao et al., 2007). Briefly, the SP2 measures rBC mass in individual rBC-containing particles using intense,

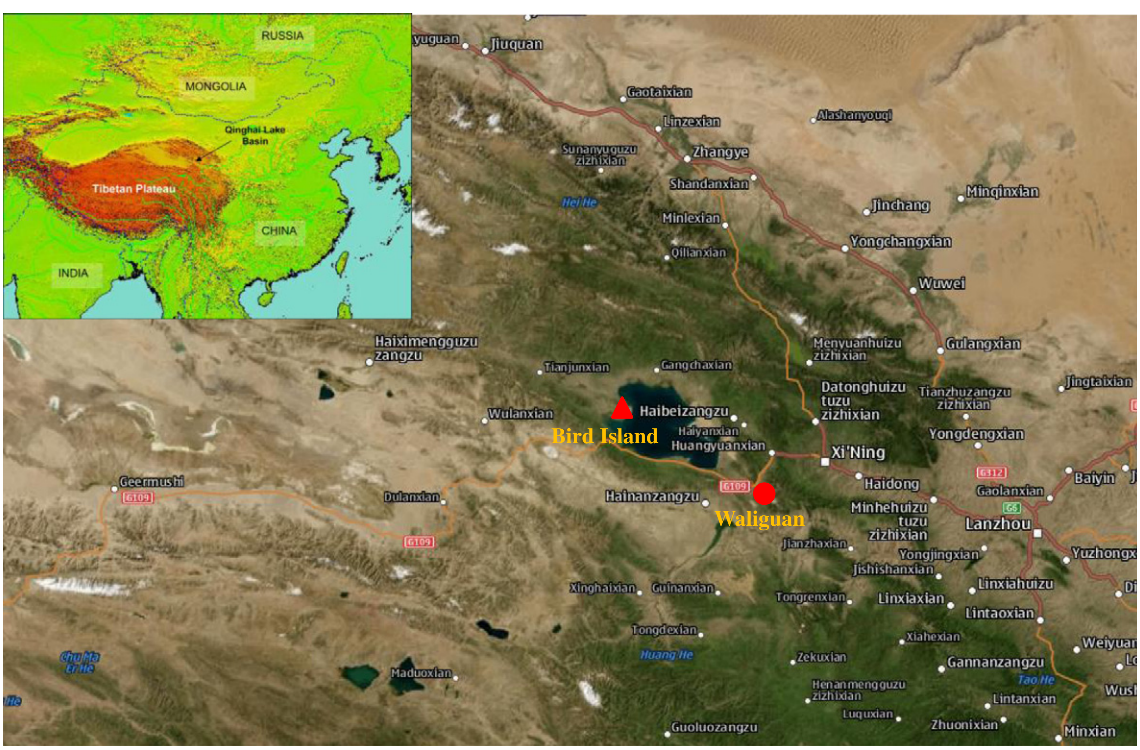

Fig. 1. Map showing the measurement site at Qinghai Lake and the surrounding region.