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Indoor air pollution from burning yak dung as a household fuel in Tibet

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HIGHLIGHTS

- Real-time BC and $PM_{2.5}$ concentrations were measured in households in Nam Co, Tibet.
- 23 households were surveyed on energy use and awareness of indoor air pollution.
- Chimney installation may not by itself ensure adequate indoor air quality.
- We observed a lower $BC/PM_{2.5}$ ratio for dung combustion than previous estimates.
- About 0.4–1.7 Gg/year of additional BC is emitted by yak dung combustion in Tibet.

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ABSTRACT

Yak dung is widely used for cooking and heating in Tibet. We measured real-time concentrations of black carbon (BC) and fine particulate matter with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) emitted by yak dung burning in six households with different living conditions and stove types in the Nam Co region, Tibet. We observed a much lower average $BC/PM_{2.5}$ mass ratio (0.013, range 0.006–0.028) from dung combustion in this area than previously reported estimates, ranging between 0.05 and 0.11. Based on our measurements, estimated fuel use, and published emission factors of BC and $PM_{2.5}$, about 0.4–1.7 Gg/year of BC is emitted by yak dung combustion in Tibet in addition to the previously estimated 0.70 Gg/year of BC for Tibetan residential sources. Our survey shows that most residents were aware of adverse health impacts of indoor yak dung combustion and approximately 2/3 of residents had already installed chimney stoves to mitigate indoor air pollution. However, our measurements reveal that, without adequate ventilation, installing a chimney may not ensure good indoor air quality. For instance, the 6-h average BC and $PM_{2.5}$ concentrations in a stone house using a chimney stove were 24.5 and 873 $\mu g/m^3$, respectively. We also observed a change in the $BC/PM_{2.5}$ ratios before and after a snow event. The impact of dung moisture content on combustion efficiency and pollutant emissions needs further investigation.

1. Introduction

Tibet is one of the most remote areas in the world and is considered one of the cleanest regions (Kang et al., 2009). Past measurements of average ambient black carbon (BC) and fine particulate matter with an aerodynamic diameter of 2.5 μm or less ($PM_{2.5}$) concentrations show 82 ng/m^3 and 2–3 $\mu g/m^3$, respectively, in Nam Co, a pastoral region in Tibet (Fig. 1) (Chen et al., 2011; Ming et al., 2010). However, indoor air pollution due to domestic biomass combustion is severe. Most residents in pastoral counties in Tibet still follow traditional nomadic lifestyles (Li et al., 2012a). With fossil fuel priced beyond their means and limited economic

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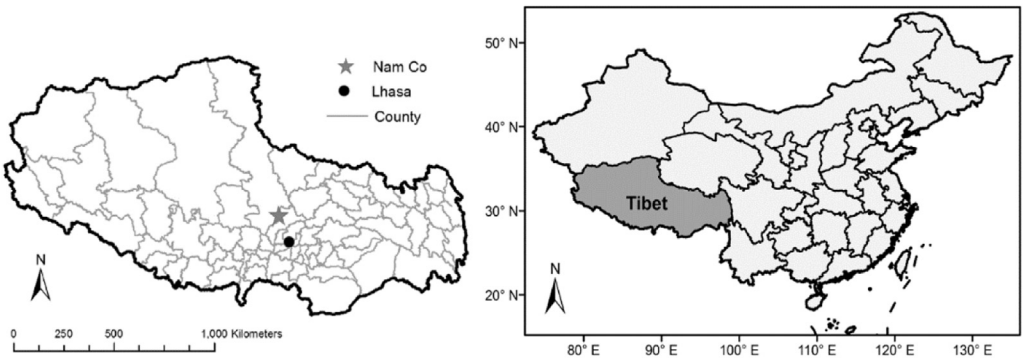

Fig. 1. Map locating the study site in Nam Co, Tibet, China.

opportunity, rural Tibetan households consume large amounts of local biomass, especially yak dung, for cooking and heating. In fact, biomass energy accounts for almost 70% of the total household energy consumption and yak dung alone accounts for more than half of residents' domestic energy consumption in this region (Gao et al., 2009; Kang et al., 2009; Liu et al., 2008).

Biomass combustion releases many air pollutants. Among them, particulate matter (PM), especially smaller PM such as $PM_{2.5}$ is noted for its association with adverse health impacts such as cardiovascular disease, respiratory disorders, and cancers (Pope and Dockery, 2006). In addition to health effects, the particles released by combustion have major climate impacts. BC, for example, is one of the largest contributors to global warming and has especially large effects in regions where the emissions are the strongest (Menon et al., 2002; Ramanathan and Carmichael, 2008). Some models indicate that BC accelerates the decrease of snow/ice cover in the Himalayan–Tibetan region and that it affects the large-scale atmospheric circulation and hydrologic cycle (Menon et al., 2002, 2010). BC is therefore often considered as a target for reducing both air pollution and near-term climate impacts, and controlling cookstove emissions is one proposed way to achieve co-benefits (Andreae and Ramanathan, 2013).

Previous studies have measured several pollutants in tents in Nam Co, Tibet. In a household using a simple stove without a chimney, the 24-h average concentrations of $PM_{2.5}$ ranged between 1270 and 1670 $\mu g/m^3$ (Chen et al., 2011; Kang et al., 2009; Li et al., 2012a, 2012b). A tent with a chimney stove had a lower 24-h average $PM_{2.5}$ concentration of 97 $\mu g/m^3$ (Chen et al., 2011), which was still approximately four-times higher than the WHO Air Quality Guideline (25 $\mu g/m^3$, 24-h mean). While previous studies measured total $PM_{2.5}$ from biomass combustion in Tibetan tents, no study quantified the BC component. Moreover, all previous studies were conducted in the summer, which is the warmest season in Tibet (monthly average temperature in August was 8.8 °C in Nam Co in 2005) (You et al., 2007). During winter or spring when the temperature is much lower (monthly average temperature in March, for example, was −5.5 °C in Nam Co in 2006) (You et al., 2007), more severe indoor air pollution is possible due to increased heating demands.

This study monitored the indoor air pollutants BC and $PM_{2.5}$ in six local households with different living conditions and stove types in Nam Co in March 2013. A survey about residents' energy use, stove operation, daily activities, and other related topics, was also conducted in 23 local households. We present average indoor pollutant levels, the BC/$PM_{2.5}$ mass emission ratio, new regional BC emissions estimates from residential combustion in Tibet, and some important case study observations regarding the impact of living environment on indoor air pollution.

2. Methodology

2.1. Study site

This study took place in the Nam Co region (30.460° N, 90.580° E, 4730m a.s.l.), a pastoral area in the southern Tibetan Plateau between March 17–23, 2013 (Fig. 1). During the study period, the average daily temperatures and precipitation were −6 °C and 2.3 mm, respectively. There were 4291 residents and 751 households registered in Nam Co in the 2000 census. Yak and sheep herding is the major occupation of most local households, and most residents follow a traditional nomadic lifestyle (Li et al., 2012a). However, about 5% of the residents also derive income from tourism.

Residents live in different types of tents/houses in the study area (Supplementary Materials S1 and S2). Both tents and houses have only one room without a separate kitchen, and people sleep, eat, and cook in the same room. Two types of tents and biomass stoves are used in this region (Kang et al., 2009; Li et al., 2012a). Briefly, traditional tents (23.2 m^3) and advanced tents (38.5 m^3) have similar structure and air ventilation conditions, but the fabric and volume differ. Simple stoves without chimneys and chimney stoves are used for both cooking and heating in this region. Simple stoves are iron circles, each of which is supported by three iron bars (50 cm in height and 40 cm in diameter). A hole (1×0.5 m^2) on top of the tent ventilates smoke from simple stoves. Chimney stoves are made of thin iron sheets, and feature a combustion chamber (40 cm in height and 40 cm in diameter), a plenum channel ($15 \times 18 \times 60$ cm^3), and a chimney (2.2 m in height and 16 cm in diameter). Yak dung is the only biomass fuel used in tents or houses in this region.

2.2. Survey procedure

The survey was designed to collect information on energy use, daily activities of household members, residents' awareness of indoor air pollution and its adverse health impacts, and their willingness to pay for indoor air pollution mitigation. Eligible subjects were residents of a typical nomadic household in Nam Co that gave oral consent to participate. Interviews took place on March 17, 18, 20, and 21, 2013 in Nam Co, in response to consent from 23 households. The survey included residents living in different tents/houses with diverse socioeconomic status and stove types. Business establishments (i.e., restaurants) and institutional settings (i.e., police services) were not included. A local resident who works as a driver and translator between Mandarin and Tibetan assisted with interviews. Questions were read to consenting, adult subjects and