Atmospheric Environment 166 (2017) 244–254

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Diagnosing Tibetan pollutant sources via volatile organic compound observations

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HIGHLIGHTS

- Industry, biomass burning, and traffic factors for VOCs are identified in Tibet.
- Different source factors present different spacial distributions in Tibet.
- Different source factors have their own specific source regions.
- The results provide support for international protection of Tibetan air quality.

ARTICLE INFO

Article history:
Received 7 March 2017
Received in revised form
9 July 2017
Accepted 17 July 2017
Available online 18 July 2017

Keywords:
Tibet
Volatile organic compounds
Tracers
Sources
Regional transport

ABSTRACT

Atmospheric transport of black carbon (BC) from surrounding areas has been shown to impact the Tibetan environment, and clarifying the geographical source and receptor regions is crucial for providing guidance for mitigation actions. In this study, 10 trace volatile organic compounds (VOCs) sampled across Tibet are chosen as proxies to diagnose source regions and related transport of pollutants to Tibet. The levels of these VOCs in Tibet are higher than those in the Arctic and Antarctic regions but much lower than those observed at many remote and background sites in Asia. The highest VOC level is observed in the eastern region, followed by the southern region and the northern region. A positive matrix factorization (PMF) model found that three factors—industry, biomass burning, and traffic—present different spatial distributions, which indicates that different zones of Tibet are influenced by different VOC sources. The average age of the air masses in the northern and eastern regions is estimated to be 3.5 and 2.8 days using the ratio of toluene to benzene, respectively, which indicates the foreign transport of VOC species to those regions. Back-trajectory analyses show that the Afghanistan-Pakistan-Tajikistan region, Indo-Gangetic Plain (IGP), and Meghalaya-Myanmar region could transport industrial VOCs to different zones of Tibet from west to east. The agricultural bases in northern India could transport biomass burning-related VOCs to the middle-northern and eastern zones of Tibet. High traffic along the unique national roads in Tibet is associated with emissions from local sources and neighboring areas. Our study proposes international joint-control efforts and targeted actions to mitigate the climatic changes and effects associated with VOCs in Tibet, which is a climate sensitive region and an important source of global water.

1. Introduction

Tibet, located in the far western area of China and surrounded by the Central Himalayas to the west and south, is one of the most remote areas and the highest plateau in the world (Xiao et al.,

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http://dx.doi.org/10.1016/j.atmosenv.2017.07.031

2015). Although few direct pollutant emissions have been observed, the environmental conditions of this unique geological and geographical unit have changed in recent decades; these changes manifest as warming trends, glacier retreat and permafrost degradation (Qiu, 2008; Yao et al., 2012; Yang et al., 2014). These changes will influence conditions on the plateau and will affect the water availability for billions of inhabitants in downstream regions distributed across more than 10 countries; they could also impact atmospheric circulation at regional and global scales (Qiu, 2008).

Mounting evidence indicates that the transport of air pollutants that have great importance to the climate system, such as BC and organic acids from surrounding areas, is the primary cause of the changes in the environmental conditions in Tibet except for the increase of greenhouse gases (GHGs) and the associated global warming (Qiu, 2008; Ming et al., 2008; Kaspari et al., 2011; Cong et al., 2015). Surrounded by the largest BC sources of East Asia and South Asia (Bond et al., 2007; Ohara et al., 2007), especially the highly populated and polluted river basin of the IGP (Fig. 1a), Tibet is primarily affected by pollutant transport from these regions (Kopacz et al., 2011; Lu et al., 2012; Zhao et al., 2013; Wang et al., 2015, 2016; Zhang et al., 2015; Li et al., 2016; Kang et al., 2016; Zhang et al., 2017). Identifying the detailed regions from which the BC originates would be valuable in prioritizing mitigation efforts in this pivotal region.

Mainly driven by the wind system, the transport pathways are usually alike for the air pollutants from a common source. Studies about different air pollutants have reported atmospheric transport from the India–Nepal–Pakistan region to Mt. Everest (Li et al., 2006), from western China, Kyrgyzstan, Tajikistan, and Pakistan to western Tibet (Kopacz et al., 2011), from Bangladesh as well as easternnorth-central and northern regions of Indian to southeastern Tibet (Cao et al., 2010; Wang et al., 2015), from the IGP of southern Asia to central Tibet (Ming et al., 2010; Xia et al., 2011), and even from the former USSR, Middle East, and eastern Europe to Mt. Everest and Tibet (Kaspari et al., 2011; Lu et al., 2012). Although they provide valuable information for the transport of BC, a large part of those studies were just confined to single-site observations. Tibet has an area of 1.2 million km^2 with complex terrain and variable meteorological conditions. Single-site observation can not reflect the situation across the whole Tibet. The other part were model simulations, which may have large uncertainties because of poor model resolution in the topographically complex region, lack of in situ and radiosonde observations, potential inaccuracies in emission inventories, and uncertainties in precipitation frequency (Zhang et al., 2017; Kopacz et al., 2011). Therefore, a good spatial-coverage in situ investigation needs to be done to construct a clearer source-receptor relationship of air pollutants in Tibet before developing out effective protection measures.

VOCs are a group of atmospheric pollutants which have similar sources to BC such as biomass burning, traffic exhaust, and industrial processes (Sarkar et al., 2014; Kopacz et al., 2011). Many individual VOCs have common sources, sometimes have unique, source specific relationships to one another. Their lifetimes, ranging from a few hours to several weeks, are comparable to regional and intercontinental transport times of air masses. These features make the combination of specific tracers and the ratios between them have strong utility to identify emission source types, regions, and related atmospheric transport (Baker et al., 2011; Helmig et al., 2008; Shim et al., 2007; Wang et al., 2003). Therefore, we apply in this study the measurements of VOCs sampled across the whole Tibet to diagnose the sources regions and related transport of pollutants to Tibet.

Considering the source type or composition at each sampling site may be different due to the uneven distribution of human activities and the associated emission sources of pollutants no matter in local or upwind regions, factor analysis using the PMF method is applied to our measurements of the VOCs tracers (Sect. 2.4). PMF is an advanced multivariate factor analysis tool that can decompose a matrix of speciated sample data into two matrices: factor contributions (G) and factor profiles (F) (US EPA, 2014). Because the factor analysis is based on the interdependencies between observed variables, the tracers indicating a similar source type or source locations will be grouped together to one factor. Thus, this method can explain the variability of tracer species concentrations by a few underlying source factors. No prior assumptions, such as meteorological conditions prevailing at the measurement sites, is required for this application. PMF can also provide the normalized contribution per sample of each factor, so we use it to explore the

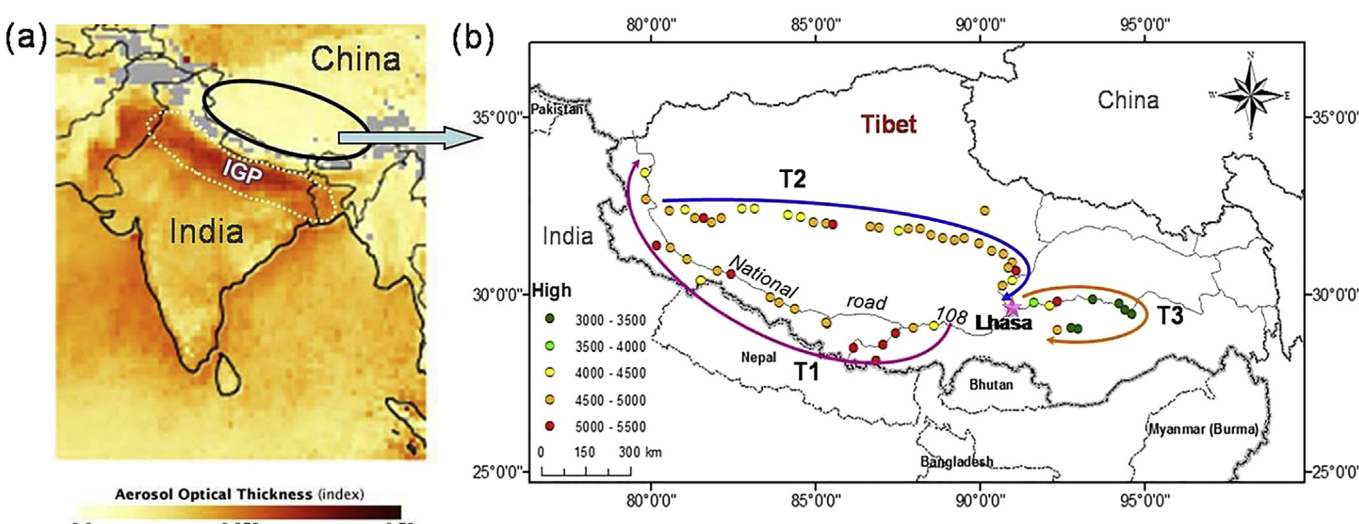

Fig. 1. (a) Location of the area of measurement in Tibet. The colors indicate the Aerosol Optical Thickness derived from data obtained from the Multi-angle Imaging Spectroradiometer (MISR) instrument on NASA's Terra spacecraft from 1 Mar 2000 to 30 Nov 2008; (b) Geographical map of Tibet that shows the sampling tracks in this study, which are ordered from T1 (Track 1, purple arrow line) to T2 (Track 2, blue arrow line) and then to T3 (Track 3, orange arrow line). The different colored dots represent the different altitudes (dark green, 3000–3500 m; light green, 3500–4000 m; light yellow, 4000–4500 m; orange, 4500–5000 m; and red, 5000–6000 m). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)