Atmospheric Environment 45 (2011) 6955–6964

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Characteristics of fine particle carbonaceous aerosol at two remote sites in Central Asia

Justin P. Miller-Schulze[a,b], Martin M. Shafer[a,b,*], James J. Schauer[a,b], Paul A. Solomon[c], Jeffrey Lantz[d], Maria Artamonova[e], Boris Chen[f], Sanjar Imashev[f], Leonid Sverdlik[f], Greg R. Carmichael[g], Jeff T. Deminter[a]

[a] Wisconsin State Laboratory of Hygiene, 2601 Agriculture Drive, Madison, WI 53718, USA
[b] Environmental Chemistry and Technology Program, 660 North Park St, University of Wisconsin, Madison, WI 53706, USA
[c] U.S. EPA, Office of Research & Development, Las Vegas, NV 89193, USA
[d] U.S. EPA, Office of Radiation and Indoor Air, Las Vegas, NV 89193, USA
[e] Institute of Atmospheric Physics, 109017 Moscow, Russia
[f] Kyrgyz-Russian Slavic University, 44 Kievskaya Str., Bishkek 720000, Kyrgyzstan
[g] Department of Chemical & Biochemical Engineering, The University of Iowa, Iowa City, IA 52242, USA

ARTICLE INFO

Article history:
Received 15 June 2011
Received in revised form
9 September 2011
Accepted 10 September 2011

Keywords:
Chemical mass balance
Source apportionment
Carbonaceous aerosol

ABSTRACT

Central Asia is a relatively understudied region of the world in terms of characterizing ambient particulate matter (PM) and quantifying source impacts of PM at receptor locations, although it is speculated to have an important role as a source region for long-range transport of PM to Eastern Asia, the Pacific Ocean, and the Western United States. PM is of significant interest not only because of its adverse effect on public health but also due to its more recently realized role in climate change. To investigate the sources and characteristics of PM in the region, a series of $PM_{2.5}$ and PM_{10} samples were collected on an every-other-day basis at two sites (termed "Bishkek" and "Teploklyuchenka") in the Central Asian nation of the Kyrgyz Republic (also known as Kyrgyzstan) for a full year from July 2008 to July 2009. These samples were analyzed using standard methods for mass, organic carbon (OC), elemental carbon (EC), water-soluble organic carbon (WSOC), water-insoluble organic carbon by difference (OC minus WSOC) and a variety of molecular marker chemical species to be used in a chemical mass balance (CMB) model to apportion the sources of OC. These analyses indicate that approximately $19 \pm 6.4\%$ of the $PM_{2.5}$ mass at both sites throughout the year consists of OC. The carbonaceous component of $PM_{2.5}$ is dominated by OC, with OC/Total Carbon (TC) ratios being around 0.8 in the winter to almost 0.95 in the summer months. The CMB analysis indicated that mobile sources, i.e., gasoline and diesel engine exhaust, biomass combustion, and biogenic secondary organic aerosol (SOA) formation from isoprene and α-pinene precursors in the summer months were the dominant sources of OC. A strong positive correlation was observed between non-biomass burning WSOC and the un-apportioned OC from the CMB analysis, indicating that some of this un-apportioned OC is WSOC and likely the result of SOA-forming atmospheric processes that were not estimated by the CMB analysis performed. In addition, a comparison of the predominant contributors to OC between the two sites indicates that biomass combustion is a stronger relative source of OC at the Teploklyuchenka site, particularly in the winter, while contributions of isoprene- and α-pinene-derived SOA to the measured OC was relatively similar between the sites.

1. Introduction

The impact on climate of atmospheric aerosol is dependent on the chemical and physical characteristics of the aerosol; as these characteristics affect the aerosol's lifetime, interaction with light, and influence on cloud formation. Carbonaceous aerosols are a significant contributor to PM concentrations around the world (Davidson et al., 2005; Solomon and Costa, 2010). These aerosols are of great interest to the scientific community due to their role in radiative forcing and, subsequently, both global and regional climate change (Haywood and Boucher, 2000), as well as due to their adverse effect on human health (Davidson et al., 2005).

However, there currently is a lack of data on carbonaceous aerosol levels and chemical speciation for a number of areas around the world, reflecting both the difficulties in PM sampling in remote

* Corresponding author. University of Wisconsin-Madison, Environmental Chemistry and Technology Program, 660 North Park St., Madison, WI 53706, USA. Tel.: +1 608 217 7500; fax: +1 608 262 0454.
E-mail address: mmshafer@wisc.edu (M.M. Shafer).

1352-2310/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.atmosenv.2011.09.026

regions and the time consuming (or complicated) analytical procedures (or methods) required for speciation. A number of approaches have been employed to fill in these data gaps, including an assortment of PM/carbonaceous aerosol modeling studies (Cooke and Wilson, 1996; Chung and Seinfeld, 2002), as well as estimations of global organic carbon (OC) and black carbon (BC) based on fuel consumption data (Bond et al., 2004). However, as with all modeling studies, accurately predicting the concentrations at sites where the regional influences are not well-characterized is challenging. For example, a 2002 study (Chung and Seinfeld, 2002) used the Goddard Institute for Space Studies Global Circulation Model II-Prime to model OC and BC concentrations for a variety of types of sampling sites around the world. The authors found that the model consistently underestimated both OC and BC at all sampling sites, which they hypothesize resulted from an underestimation of OC and BC emissions in the model input and/or an overestimation of wet scavenging by clouds.

Our understanding of the role of aerosols in processes that affect climate (and, consequently, the policy actions taken regarding these aerosols) is based on our knowledge of their chemical and physical characteristics. This understanding is, in many cases, based on our ability to incorporate aerosol effects into climate models. The chemical and physical characteristics of aerosols are necessarily a function of their source. For example, biomass combustion produces OC that is predominantly water-soluble (Sannigrahi et al., 2006), whereas diesel fuel combustion produces relatively less water-soluble OC (Cheung et al., 2009), due to differences in fuel type and combustion temperature. Processes affecting climate, such as cloud formation, will be affected differently by aerosols from these two sources. The effect of chemical characteristics of aerosols on cloud formation, aerosol lifetime, and regional transport illustrates the importance of understanding the sources of atmospheric aerosol. While emissions inventories based on fuel consumption data have been employed for this purpose, as noted above, these inventories potentially exclude the contributions to atmospheric PM by sources that are not well estimated from fuel usage, such as secondary organic aerosol and other primary non-combustion sources. As such, detailed measurements and source apportionment of aerosols in understudied regions is an important first step in establishing the relevant chemical characteristics and sources of PM; this knowledge can then be applied to existing and future modeling studies to constrain model inputs and evaluate the performance of model outputs.

Central Asia is one of the areas for which very little detailed chemical data on ambient PM exists. However, recent work suggests that East-Central Asia may be an important source region for PM involved in long-range transport to, for example, the U.S. (Fischer et al., 2009). The Gobi and Taklamakan Deserts in western China and Mongolia are thought to be the source of much of this transported PM (Fischer et al., 2009), though aerosol from the Aral Sea region in Central Asia is also likely contributing. The volume of the Aral Sea has decreased markedly over the last half-century, due to intensive irrigation using waters from the feeder rivers, and as a result, parts of the Aral Sea region have been transformed into an open salt desert (Singer et al., 2003). This has resulted in an increased frequency of dust storms in the region (O'Hara et al., 2000), events that could influence the areas further east of the Aral Sea and supplement other major dust sources. Because of the lack of data on the chemical characteristics of the PM in Central Asia, it is unclear what the impact of dust storms originating from the Aral Sea zone and other PM source regions in Central Asia are on both regional and global levels of PM.

The data presented in this manuscript is one component of a larger project comprised of a full year of every-other-day PM sampling that was conducted at two sites in the Kyrgyz Republic (also known as Kyrgyzstan) from mid-July 2008 through mid-July 2009. The overarching goal of the study was to obtain a detailed chemical characterization of the ambient PM collected in the Kyrgyz Republic during the sampling period and to estimate the contribution of the sources of this aerosol to the regional and transcontinental flow of PM. Because detailed data on point and non-point sources of aerosol are not readily available for this area, the receptor-based analysis presented is a mechanism to address the relevant sources of PM in the region. Results presented here focus on the carbonaceous components of the collected PM, and the resulting chemical mass balance (CMB) analysis of the OC fraction to investigate the sources of this component of the aerosol.

2. Experimental

2.1. Description of sampling region

The Kyrgyz Republic is bordered by China to the east, Kazakhstan to the north, Uzbekistan to the west, and Tajikistan to the south. The Aral Sea region lies 1200 km to the west. The terrain in the Kyrgyz Republic is quite mountainous, and the majority of the population lives in rural areas (65%). The total population of the country as of 2008 is approximately 5.4 million with a significant fraction (approximately 825,000 as of 2009) living in the largest city and capital of the country, Bishkek (http://www.placesdata.com/world/kyrgyzstan/bishkek/). The location of the Kyrgyz Republic in Central Asia is shown in Fig. 1. Although a detailed emissions inventory was not available for this study, our knowledge of the region suggests that most electricity is generated by hydroelectric power plants. Coal-fueled electropower stations are used in urban areas to produce hot water for residential heating, whereas in more rural areas, heat is produced by a combination of electricity, residential coal stoves, and wood and dung (i.e., biomass) combustion.

2.2. Sample collection and filter compositing

PM samples (24 h) were collected at the two sampling sites, Bishkek and Teploklyuchenka (abbreviated as "Teplo." where space constraints necessitate), from mid-July 2008 to mid-July 2009 on an every-other-day basis. The approximate locations of the sampling sites are shown in Fig. 1. The Bishkek sampling site was located 23 km south of the Bishkek city center, at 42° 40′ 47.80″ N, 74° 31′ 44.30″ E. Bishkek has a land area of ~127 km^2 (http://www.statoids.com/ukg.html). The Teploklyuchenka sampling site, at an elevation

Fig. 1. Map of Central Asia and location of the Aral Sea relative to the Kyrgyz Republic, as well as approximate location of sampling sites within Kyrgyz Republic (inset). See text for coordinates.