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Space-borne and ground observations of the characteristics of CO pollution in Beijing, 2000–2010

Lingjun Li [a], Yang Liu [b,*]

[a] Beijing Municipal Environmental Monitoring Center, Beijing 100048, China

[b] Department of Environmental Health, Rollins School of Public Health, Emory University, Atlanta, GA 30322, USA

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ABSTRACT

Both the long-term and short-term variability of carbon monoxide (CO) pollution in Beijing metropolitan area, China are studied with 11 years of MOPITT observations and 10 years of ground measurements. The impact of the 2008 Beijing Olympic Games on regional air quality is also examined. MOPITT CO columns exhibit different temporal patterns from ground CO concentration measurements. MOPITT CO column in August has gradually increased from 2000 to 2007, even though ground level CO concentrations have significantly decreased due to continued local air pollution control effort. Both CO columns and ground CO concentrations were reduced due to strict albeit temporary emissions control measures from July to September 2008 to support the Beijing Olympic Games. However, the reduction of total CO columns (~13%) was less pronounced than ground CO concentration (~44%), indicating that local emission control effort was partially offset by the continuously deteriorating regional air quality. In addition, MOPITT CO mixing ratio profiles indicate a significant regional pattern at higher altitudes. CO total columns after 2008 show an overall increasing trend, in contrast to the decreasing trend observed in ground measurements.

1. Introduction

Carbon monoxide (CO) is a toxic gas produced as a by-product of combustion. Inhaling even relatively small amounts of the gas can lead to hypoxic injury, neurological damage, and even death. On average, exposures at 100 ppm or greater is dangerous to human health (Prockop and Chichkova, 2007). The heart is one of the most sensitive organs to hypoxia caused by carbon monoxide. Carbon monoxide exposure may lead to a significantly shorter life span due to heart damage (Henry et al., 2006). In addition, CO plays a central role in atmospheric chemistry by acting as the largest sink of hydroxyl radicals and through its role in the production of ozone. Therefore, it has a major influence on the oxidizing power of the atmosphere and the global composition of air pollutants.

CO is one of the criterion ambient air pollutants in China. The Beijing municipality has made significant efforts to improve air quality during the 2008 Summer Olympic Games and Paralympic Games. From July 20 to September 20, multiple control measures were enforced including removing approximately one-half of the on-road vehicles (~1.5 million) off the road on alternate days under an even-odd license plate system, temporarily closing or limiting the production of major polluting industries, temporarily shutting down construction activities and coal-burning boilers, and enhancing street cleaning. In addition, emission control measures were implemented in neighboring Tianjin municipality, Hebei, Shanxi, Shandong provinces, and Inner Mongolia Autonomous Region during this period (Fig. 1).

Major anthropogenic sources of CO emissions in China include industry, residential heating, and transportation (Zhang et al., 2009b). As of September 2010, there are over 4.5 million on-road vehicles and over 22 million permanent residents in Beijing (http://gs.people.com.cn/GB/183355/12754795.html, http://www.chinadaily.com.cn/china/2010-02/26/content_9511839.htm, accessed on October 31, 2010). In addition, combustion of approximately 30 million tons of coal for power and heating supply (2007 value) in Beijing (http://www.bjstats.gov.cn/tjnj/2009-tjnj/content/mV69_0404.htm, accessed on October 31, 2010) also contributes to the CO pollution in Beijing. CO is considered as an important indicator of overall air quality of Beijing. To date, the variability of ground level CO in Beijing has been studied using one-year worth of measurements (Xue et al., 2006), but the interannual variability of CO total column and its relationship with ground level CO as well as CO vertical distribution have not been reported. We characterized the spatial and temporal distribution of column CO concentrations over Beijing retrieved by the

* Corresponding author.
E-mail address: yang.liu@emory.edu (Y. Liu).

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Fig. 1. Locations of the study sites (Dingling as the Beijing background, Huhhot near major coal-burning power plants, Taiyuan in major coal production region, and Mt. Waliguan as the continental background). Temporary emissions control measures during the 2008 Summer Olympic Games were taken in Beijing (dark grey region) and the surrounding provinces (light gray regions).

Measurement of Pollution in the Troposphere (MOPITT) instrument between 2000 and 2010, and compared with ground measurements. In addition, we also compared the CO trend in Beijing with other sites in northern China in order to evaluate the impact of emission control measures on the air quality of Beijing and surrounding regions.

2. Data and method

The MOPITT instrument was launched aboard the NASA Earth Observing System Terra spacecraft in 1999 to a Sun-synchronous orbit with a 10:30 local equator crossing time. MOPITT was designed to operate by sensing infrared (IR) radiation from either thermal IR emission/absorption at 4.7 μm for CO profiles, or reflected solar radiation in the near-IR at 2.2–2.4 μm for CO and methane column measurements during daytime. MOPITT is equipped with gas correlation radiometers incorporating both length modulation and pressure modulation cells operating in two distinct spectral bands: the near-infrared (NIR) CO overtone band near 2.3 μm and the thermal infrared (TIR) fundamental band near 4.7 μm. The NIR radiances provide information with respect to the CO total column with very weak sensitivity to the vertical distribution of CO whereas the TIR radiances are sensitive to differences in CO concentrations over broad layers in the troposphere (Deeter et al., 2009). MOPITT CO measurements have been used in air quality monitoring in a few case studies. For example, Clerbaux et al. demonstrated that the CO pollution arising from large cities and urban areas can be distinguished from background transported pollution by selecting and averaging MOPITT data over long time periods (Clerbaux et al., 2008). Dayside MOPITT retrievals in the lower troposphere have been shown to provide useful information on surface sources of atmospheric CO over the Indian subcontinent (Kar et al., 2008). In addition, using CO data from MOPITT together with a chemistry transport model, Pfister et al. estimated the wildfire emissions in Alaska and Canada in the summer of 2004 (Pfister et al., 2005). It has also been reported that the trans-Pacific transport of CO patterns are well captured with the global chemistry and transport model LMDz-INCA based on the complementary pictures provided by the satellite measurements from MOPITT, SCIAMACHY and ACEFTS (Turquety et al., 2008). In the current analysis, we collected Version 4 MOPITT level 2 daily (MOP02.004, 22 km $\times$ 22 km) CO total column and mixing ratios as well as level 3 gridded monthly mean (MOP03 M.004, $1^\circ \times 1^\circ$) CO total column (ftp://l4ftl01.larc.nasa.gov/MOPITT) over Beijing, China between 2000 and 2010. To compare the temporal pattern of CO regional pollution in Beijing with other regions in northern China, we also collected CO column data over Huhhot (capital city of Inner Mongolia near multiple major coal-burning power plants), Taiyuan (capital city of Shanxi Province, major coal production region in China), and Mt. Waliguan (in Qinghai Province, continental background; Zhou et al., 2004) (Fig. 1). MOPITT level 3 data were selected by matching city or site centroids to nearest $1^\circ \times 1^\circ$pixel center. Level 2 data were selected to cover Beijing and its surrounding provinces (36–43 N, 113–123 E). Retrieval bias drift in Version 4 MOPITT CO data is typically about 1 ppbv yr^{-1} for levels in the mid troposphere, and about 2 ppbv yr^{-1} in the upper troposphere (Deeter et al., 2010).

Ground level CO concentrations in Beijing were collected by the Beijing Municipal Environmental Monitoring Center. CO was measured with commercial, non-dispersive, infrared gas filter correlation analyzers (Thermo Fisher Scientific Inc., Waltham MA, USA). Hourly CO concentrations from 2000 to 2009 were collected from eight urban sites, and averaged to represent Beijing local conditions. Data from the Dingling site (50 km north of city center, surrounded by forest and pastures, distant from highways or major point sources) were used as Beijing's urban background. Unfortunately, ground-level CO measurements are not accessible for the other sites because local environmental protection agencies in China are only required to publish the daily levels of the dominant air pollutant among sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and inhalable particulate matter (PM_{10}).

3. Results and discussion

3.1. Seasonal variations of CO in northern China

3.1.1. Seasonal trend of MOPITT CO columns

To smooth out the inter-annual variability in CO concentrations, we calculated monthly mean MOPITT CO column using 2000–2009 data in Beijing and three other sites in northern China. As shown in Fig. 2, the CO columns are highest in Beijing and lowest in Mt. Waliguan, and Taiyuan and Huhhot stay in between. Because CO is the primary air pollutant related to fossil fuel combustion and biomass burning and MOPITT CO columns are more sensitive to free

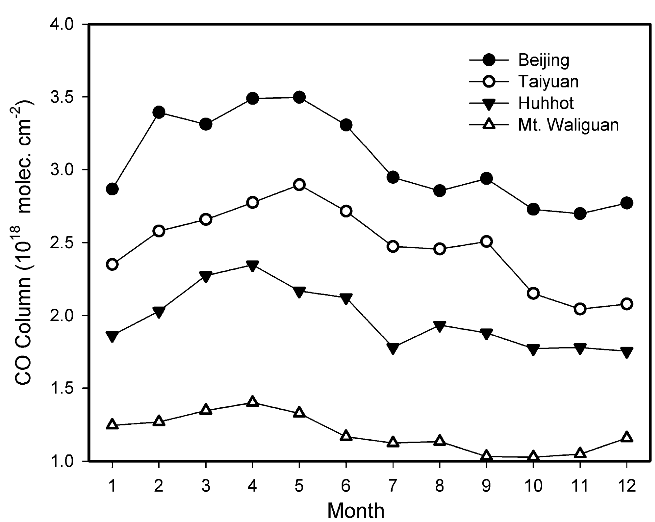

Fig. 2. Monthly trend of CO average column concentrations in northern China (2000–2009). Note that MOP03M.004 data is available since March 2000, and data in June and July of 2001 and August and September of 2009 are missing.