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An integrated approach to identify the biomass burning sources contributing to black carbon episodes in Hong Kong

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HIGHLIGHTS

- Indicators affirm the impact of biomass burning on Hong Kong during BC episodes (2010).
- Contributing sources are identified by satellite data analysis and model simulations.
- The Indochina/SW China region is the dominant source in spring/winter, with influence also evident from Africa and India.

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ABSTRACT

Biomass burning is the largest source of primary fine carbonaceous particles and globally the second largest source of trace gases, contributing to climate change and regional air pollution. This study investigates the most serious black carbon (BC) episodes in Hong Kong in 2010, which occurred on 22 February, 18 March, 6, 20 and 21 December. The contributing sources were identified using an integrated approach of ground-based measurement, satellite data analyses and model simulations. Hourly maximum BC concentrations from continuous monitoring ranged from 15.6 to 18.9 μg m^{-3}. The correlation coefficients between hourly BC and carbon monoxide (CO) concentrations (CO as an indicator of biomass burning) varied from 0.88 to 0.97 during episodic/high BC days whereas daily ΔBC/ΔCO ratios for the episodes were between 9.05 and 13.1 ng m^{-3} $ppbv^{-1}$, significantly higher than the seasonal averages. Non-sea-salt (nss)-K^+ (daily), another indicator of biomass burning, correlated moderately with BC ($r = 0.52$) for concentrations above the 80th percentile. The area-averaged statistics for fire pixel counts from satellite measurement showed the intensity of biomass burning in 2010 was strongest in Africa, Southwest China and Indochina, followed by North/Central, South China and India. Except for North/Central China, all sources are upwind of Hong Kong when the northeast monsoon and the mid/upper-tropospheric westerlies (subtropical jet) prevail. GEOS-Chem simulations indicate that biomass burning contributed most significantly from Indochina (southwest China included) in the spring of 2010. This model sensitivity analysis complements the MODIS-based fire map(s), the high-level vector wind plots, the AIRS CO and backward trajectory analyses. Results suggest that other contributors of BC include not only South China, but also the Indian subcontinent (in spring) and Africa in winter. The latter's influence is evident in the February and December episodes.

1. Introduction

Black Carbon (BC) originating from biomass burning dominates the overall atmospheric BC burden, contributing to as much as 42% of the global BC emissions, while the combustion of fossil fuels and the use of biofuels make up 38% and 20%, respectively (Bond et al., 2004). Emissions from biomass burning not only affect urban and regional air quality, but also have important effects on the radiative budget of the atmosphere, for example, BC has been estimated to contribute as much as 50% of the 1.9 °C warming in the Arctic since 1890 (Shindell and Faluvegi, 2009). In addition to the particle bound BC, biomass burning is also a significant source of greenhouse gases (Cicerone, 1994).

Biomass burning originating in Asia has attracted much attention in previous decades. Kondo et al. (2004) reported on the

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impacts of biomass burning in Southeast Asia on ozone and reactive nitrogen over the Western Pacific in spring. Aircraft measurements during the TRACE-P field experiment indicated that biomass burning emissions were a significant source of CO, BC, organic carbon (OC), and hydrogen cyanide (HCN) in Southeast Asia. Chan et al. (2000, 2003) show that ozone-rich air masses from biomass burning emissions passed through the Indo-Burma region in the dry spring season and caused elevated ozone levels over Hong Kong. Deng et al. (2008) have found that the Pearl River Delta (PRD) was similarly affected. Biomass burning in Indonesia caused large-scale haze in 2006 and was reported to spread to as far as South Korea in October (NASA, 2006), and possibly Hong Kong as well.

Air pollution episodes induced by biomass burning are often accompanied by increased signature pollutant levels. CO originating from biomass burning, for example, is about twice that from fossil fuel combustion on the global scale (Holloway et al., 2000). Often the ratio of BC and CO has been used to identify the origin of BC from biomass burning. A strong positive correlation was observed by Spackman et al. (2008) between simultaneous measurements of BC and CO in Texas, based on results showing BC/CO ratios of 9.0 ng m^{-3} $ppbv^{-1}$ for a fresh biomass burning plume, and 5.8 ng m^{-3} $ppbv^{-1}$ for outflows from urban and industrial areas. Higher ΔBC/ΔCO (with background BC and CO concentrations subtracted) ratios of 10.3 and 11.6 were obtained for two biomass burning plumes in Mt. Huang (East China), compared with 8.8 and 6.5 for plumes from urban East/North/South China (Pan et al., 2011). A significant ratio of 14.3 ng m^{-3} $ppbv^{-1}$ was also reported for open crop residue burning at Mt. Tai (Pan et al., 2012). Higher ΔBC/ΔCO ratios are, therefore, often used as indicator of biomass burning. On the other hand, major inorganic species from biomass burning were found to be potassium, followed by chloride, nitrate, and sulfate ions (Silva et al., 1999). Zheng et al. (2005) used the K^+/OC(organic carbon) ratio to distinguish biomass burning from other OC sources while Li et al. (2010a) found the potassium concentration and K^+/PM_{10} ratio drastically increased in Shanghai during the summer harvest time of 2009. Additionally, many researchers used organic markers as source tracers for biomass burning. Zhang et al. (2010) found a build-up of levoglucosan and non-sea-salt potassium during two episodes in Guangzhou during the summer of 2006. Yuan et al. (2010) identified biomass burning plumes in Guangzhou and a rural site in the PRD using acetonitrile as tracer.

Although mostly originating from rural areas, plumes from biomass burning have been reported to travel long distances to urban regions, significantly contributing to urban pollution, for example: in Shanghai in 2009 (Li et al., 2010a) and the haze in Beijing in 2007 (Li et al., 2010b). In the northeast monsoon season, regional biomass burning emission was also found to have significant influence on carbonaceous aerosol levels in South China (Zhang et al., 2010). On a global scale, Hadley et al. (2007) have estimated that long-range transport of BC and fine particulate matter ($PM_{2.5}$) from Asia contributed as much as 75% of BC in North America during April 2004 and approximately 78% of the BC transport occurred in the mid-troposphere above 2 km. Since the 1980s, Africa has experienced the highest deforestation rates globally (http://rainforests.mongabay.com/congo/). The burning of tropical savannas (grass, bush savanna or savanna woodland) is estimated to emit nearly three times as much carbon as does the burning of tropical forests (Levine et al., 1995). Although biomass burning originating in Asia has been well documented, few studies have investigated the potential impact of transcontinental biomass burning emissions on Asia. In this study, we present an integrated investigation approach, including ground-based measurement, satellite data analysis, chemical transport and back trajectory models, to identify the regional and global biomass burning emission sources that contributed to the most severe black carbon episodes in Hong Kong in 2010. Distant origins of biomass burning from Africa were also investigated.

Fig. 1. Map of Hong Kong and part of the (Pearl River Delta (PRD)), based on Croquant, 2007.

2. Data and methods

2.1. Monitoring data

Continuous air monitoring and time integrated particulate matter sampling were carried out from January to December, 2010, in Tung Chung, Hong Kong (shown in Fig. 1). The Tung Chung station is located at a height of 21 m above ground on the rooftop of a health centre, about 20 km southwest of the urban center of Hong Kong and 3 km south of the Hong Kong International Airport. The site has been characterized by influences from both local and regional emission sources (Wang et al., 2003). Ground-based measurement data were analyzed first in an attempt to differentiate local from remote sources.

Air pollution data including BC, CO, PM_{10}, NO_x and the chemical composition of PM_{10} (potassium, aluminum, calcium, selenium, chloride, sulfate, nitrate, ammonium, etc.) for the period of January to December, 2010 were acquired from the Environmental Protection Department of the Hong Kong SAR (HKEPD). Black carbon was measured by both time integrated daily PM_{10} sampling as well as continuous real time sampling (hourly resolution) by an Aethalometer (AE31, Magee Scientific) installed at Tung Chung in western Hong Kong (Fig. 1). In the continuous method, light transmission analysis determines the mass concentration of BC collected on a filter at 880 nm. CO, NO_x and PM_{10} data were available on an hourly basis from routine continuous monitoring while the chemical composition of PM_{10} was measured once every six days for 24 h samples. Data provided by the HKEPD had been subject to stringent QA/QC procedures following USEPA requirements. Non sea-salt potassium in PM_{10}, referred to as nss-K^+ hereafter, was calculated from $[K^+ - 0.0355{*}Na^+]$ (Zhang et al., 2010). Background BC and CO concentrations are approximated as the 1.25th percentile (1.96σ) of the hourly BC and CO data following Han et al. (2009)' method. Seasonal BC and CO background concentrations are shown in the Supplementary Information S1.

2.2. Satellite products

The MODIS-Terra derived area-averaged time series and area statistics of Cloud and Overpass Corrected Fire Pixel Count and the MODIS-Aqua Derived Fire Radiative Power from the Northern