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Source apportionment of volatile organic compounds measured in Edmonton, Alberta

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HIGHLIGHTS

- VOC samples from two sites were analyzed using positive matrix factorization.
- Eleven factors were identified using a large number of chemical species available.
- Factors were identified as industrial, transportation, biogenic and global.
- The study illustrates the importance of sitting in characterizing emissions sources.
- Combined dataset from the two sites allowed for robust source characterization.

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ABSTRACT

From 2003 to 2009, whole air samples were collected at two sites in Edmonton and analyzed for over 77 volatile organic compounds (VOCs). VOCs were sampled in the downtown area (Central site) and an industrial area on the eastern side of the city (East site). Concentrations of most VOCs were highest at the East site, with an average total VOC mass concentration of 221 μg m^{-3}. The average total VOC mass concentration at the Central site was 65 μg m^{-3}. The United States Environmental Protection Agency's positive matrix factorization receptor model (EPA PMF) was used to apportion ambient concentrations of VOCs into eleven factors, which were associated with emissions sources. On average, 94 and 99% of the measured mass were apportioned by PMF at the East and Central site, respectively. Factors include transportation combustion (gasoline and diesel), industrial sources (industrial evaporative, industrial feedstock, gasoline production/storage, industrial chemical use), mixed mobile and industrial (gasoline evaporative, fugitive butane), a biogenic source, a natural gas related source, and a factor that was associated with global background pollutants transported into the area. Transportation sources accounted for more than half of the reconstructed VOC mass concentration at the Central site, but less than 10% of the reconstructed mass concentration at the East site. By contrast, industrial sources accounted for ten times more of the reconstructed VOC mass concentration at the East site than at the Central site and were responsible for approximately 75% of the reconstructed VOC mass concentration observed at the East site. Of the six industrial factors identified at the East site, four were linked to petrochemical industry production and storage. The two largest contributors to the reconstructed VOC mass concentration at the East site were associated with fugitive emissions of volatile species (butanes, pentanes, hexane, and cyclohexane); together, these two factors accounted for more than 50% of the reconstructed VOC mass concentration at the East site in contrast to less than 2% of the reconstructed mass concentration at the Central site. Natural gas related emissions accounted for 10%–20% of the reconstructed mass concentration at both sites. Biogenic emissions and VOCs associated with well-mixed global background were less than 10% of the reconstructed VOC mass concentration at the Central site and less than 3% of the reconstructed mass concentration at the East site.

1. Introduction

Volatile organic compounds (VOCs) are important precursors to ozone (Chameides et al., 1992; Carter, 1994), can form secondary

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organic aerosols (Ng et al., 2007), and are among the most important ambient carcinogens (McCarthy et al., 2009; U.S. Environmental Protection Agency, 2011). Understanding the temporal and spatial characteristics of VOCs gives insight into emissions sources to which mitigation measures can be applied to improve air quality and reduce human health impacts.

Previous source apportionment efforts using Positive Matrix Factorization (PMF) on VOCs have been performed on data collected in areas such as Los Angeles, CA, Houston, TX, and Shanghai, China (e.g., Brown et al., 2007; Leuchner and Rappenglück, 2010; Cai et al., 2010), as well as other locations across the world (Mukund et al., 1996; Jorquera and Rappenglück, 2004; Gaimoz et al., 2011; Sauvage et al., 2009; Bon et al., 2011). PMF requires only ambient data; assumptions regarding the number or types of sources or specific source profiles are not explicitly needed (Paatero and Tapper, 1994). In the Los Angeles, CA study Brown et al. (2007) found five- or six-factor solutions at two sites (Azusa and Hawthorne) where transportation related factors accounted for 71–80% of total reconstructed VOC mass concentration. In the Houston, TX study at the Moody Tower site near the Houston Ship Channel, eight-factors were identified, of which industrial sources accounted for approximately two-thirds of the reconstructed VOC mass concentration (Leuchner and Rappenglück, 2010). In the Shanghai, China study, seven-factors were identified at the central Shanghai site, of which transportation sources accounted for 40% of reconstructed mass concentration (Cai et al., 2010).

Edmonton is the capital of the Canadian province of Alberta and is the sixth largest metropolitan area in Canada, with a 2011 population of 1.16 million residents (http://www.statcan.gc.ca/) in the metropolitan area. Edmonton has a cold continental climate and is home to a variety of manufacturing and heavy industries, including oil and gas refining and chemical manufacturing.

Previously Chen et al. (1997) examined the seasonal variability of VOCs in Edmonton using data collected between 1991 and 1993 and examined the contribution of the most abundant VOC species. They found that at the Central site, maximum values occur in winter and minimum values in summer, likely as a result of meteorological changes in mixing height and ventilation. Seasonal changes were not detected at the East site owing to higher summer emissions from nearby industrial sources.

In this study, PMF is applied to data collected between 2003 and 2009 to determine potential emissions sources for VOCs measured at two Edmonton sites. Whole air samples (24-hr integrated) were collected at two sites in Edmonton: Central (Downtown area) and East (an industrial area on the eastern side of the city). The samples were collected on a one-in-six day sampling schedule and analyzed for over 77 VOCs. The resolved factors, their potential sources, and temporal variation are discussed. The wind direction(s) and season(s) associated with elevated concentration are also included in the discussions when appropriate.

While many studies have examined VOC emissions sources using PMF and other source apportionment tools, this study provides three novel features. Firstly, the relatively large number (77) of chemical species available over a multi-year period for use in this study resulted in the ability to identify a larger number of factors than any other VOC PMF study to date of which we are aware. Many of the previous PMF studies comprised 30–50 chemical compounds (Brown et al., 2007; Leuchner and Rappenglück, 2010; Cai et al., 2010). A smaller chemical compound list will generally limit the ability of a source apportionment tool to find factors, especially when so many of the species are co-emitted by sources. A more expansive compound list provides more information for source characterization.

Secondly, this study dramatically illustrates the importance of siting considerations in understanding emissions sources

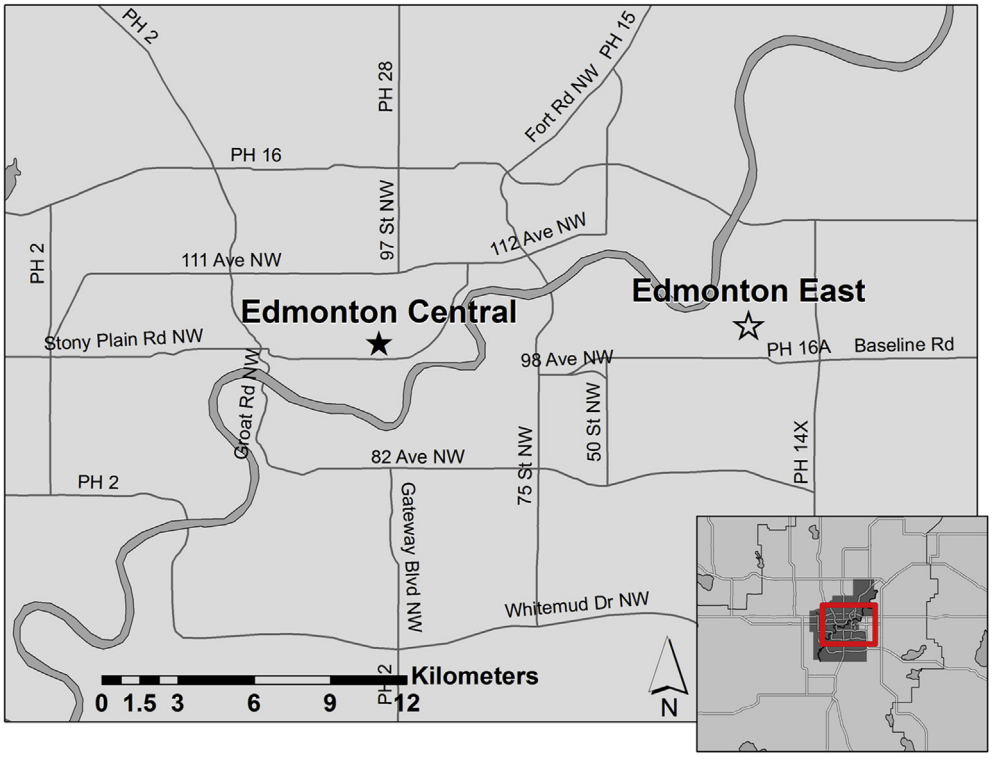

Fig. 1. Location of the Edmonton sampling sites used in the current study.