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Characterization of air quality and fine particulate matter sources in the town of Hinton, Alberta

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ABSTRACT

With concern in recent years about dust issues and fine particulate matter ($PM_{2.5}$) levels approaching a new Canadian Ambient Air Quality Standards (CAAQS), an investigation of air quality characteristics and potential sources influencing $PM_{2.5}$ concentrations was undertaken in the community of Hinton, Alberta. The study was conducted for the period November 2013 to February 2016 using hourly concentrations of criteria air pollutants. Comparatively higher concentrations of $PM_{2.5}$ were observed in summer (mean: 12.5 μg/m^3, median: 8.0 μg/m^3) than in winter (mean: 7.5 μg/m^3, median: 6.0 μg/m^3).

The 3-year averages of annual average $PM_{2.5}$ concentrations (8.1–8.9 μg/m^3) were below the 2015 annual CAAQS value of 10 μg/m^3. Exceedances of a 1 h Alberta Ambient Air Quality objective (58 times > 80 μg/m^3) and a 24 h CAAQS (16 times > 28 μg/m^3) were observed at Hinton for the study period and occurred during summer months primarily due to occurrence of forest fire episodes. A multivariate model positive matrix factorization (PMF) revealed five sources. Background dust and secondary aerosol was identified as the largest source contributing 68% to $PM_{2.5}$ mass. Other sources included traffic (13.4%), an O_3-rich source (12.7%), industry (3.1%) and a mixed source (3.1%). These findings offer preliminary information about contributions of different sources to $PM_{2.5}$ at Hinton; and this information can support policy makers in developing appropriate management initiatives for reducing dust and secondary particulate matter pollution.

1. Introduction

Ambient monitoring of criteria air pollutants e.g., fine particulate matter ($PM_{2.5}$), ground-level ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) is of interest due to their potential link to adverse human health outcomes from exposure (Burnett et al., 1998, 1999, 2004; Ruidavets et al., 2005; Pope et al., 2014; Weichenthal et al., 2014). In addition, high concentrations of these pollutants are reported to contribute to acid deposition, photochemical smog and reduced atmospheric visibility (Cooper and Alley, 2002; Cheung et al., 2005). New air quality standards for $PM_{2.5}$ – i.e., Canadian Ambient Air Quality Standards (CAAQS) – were developed in Canada in 2012 through a collaborative process with federal, provincial and territorial governments and other stakeholders (CCME, 2012). The new CAAQS for $PM_{2.5}$ for the year 2015 (annual: 10 μg/m^3, 24 h: 28 μg/m^3) and 2020 (annual: 8.8 μg/m^3, 24 h: 27 μg/m^3) replace the former 24 h Canada-Wide Standard (CWS) of 30 μg/m^3 established in 2000 (CCME, 2000).

The Valley-area of Hinton (population 9,882, area 33.52 km^2) (Statistics Canada, 2016) is a small community in the Upper Athabasca air zone in west-central Alberta (Fig. S1a). The Government of Alberta (Alberta Environment and Parks, 2015) recently evaluated $PM_{2.5}$ and O_3 in Alberta air zones for the time period of 2011–2013, including the Upper Athabasca airshed where Hinton is situated. It reported that an air quality monitoring station at Hinton had annual and 24 h $PM_{2.5}$ metric values of 8.1 μg/m^3 and 19 μg/m^3. Alberta Environment and Parks (2015) had established four-color coded air quality management thresholds for 2015 $PM_{2.5}$ and O_3 in Alberta (Table S1), and it assigned the Hinton station to an orange management level for $PM_{2.5}$ – indicating that $PM_{2.5}$ concentrations were approaching the new CAAQS and proactive planning and/or action may need to be considered to prevent exceedances. Historical reports had also existed about air quality concerns related to nuisance and other complaints from dust, odor and wood burning

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smoke in Hinton (Hinton, 2014; CASA, 2014; Town of Hinton, 2014, 2015). It was therefore of interest to undertake a study to examine $PM_{2.5}$ levels and to identify different emission sources that affect $PM_{2.5}$ levels in Hinton.

Under the National Air Pollution Surveillance (NAPS) monitoring program, Environment Canada only performs $PM_{2.5}$ speciation measurements in selected major urban centers of Canada (e.g., Vancouver, Edmonton, Toronto, Montreal). Local airshed monitoring organizations licensed by the environment department in Alberta (Alberta Environment and Parks) operate air quality monitoring networks and monitoring stations throughout Alberta (in cities, small towns and rural areas) and measure real-time concentrations of gaseous pollutants and $PM_{2.5}$. Receptor models like principal component analysis (PCA) and positive matrix factorization (PMF) have been widely used to identify and apportion emission sources using $PM_{2.5}$ chemical speciation data. However, receptor modeling using $PM_{2.5}$ speciation data is often time-consuming and cost-intensive. It is not surprising that many of the monitoring organizations do not have capabilities and financial resources to routinely monitor for chemical species in particulate matter. This is the case for the organization responsible for air quality monitoring in Hinton.

Given the fact that chemical composition of particulate matter data is not available for most air quality monitoring stations worldwide, numerous studies have been carried out to investigate sources and origins of ambient fine particulate matter, nanoparticles, particle size distribution using real-time concentrations of gaseous pollutants data and meteorological parameters (e.g., Yue et al., 2008; Thimmaiah et al., 2009; Hellebust et al., 2010; Sun et al., 2014; Khan et al., 2015; Al-Dabbous and Kumar, 2015; Sowlat et al., 2016). PCA has been used (Cheng et al., 2009; Hellebust et al., 2010; Parsons et al., 2013; Khan et al., 2015) to identify and characterize emission sources of $PM_{2.5}$, particle size distribution and atmospheric mercury using gaseous pollutants data. However, compared to PCA, PMF provides a better fit to ambient data, offers non-negative source factors, error estimates and better data treatment including handling of missing values and values below the detection limit (Paatero and Tapper, 1994). To the best of our knowledge, numerous source apportionment studies have been done to date by applying the PMF model to determine emission sources using real-time gaseous pollutant data (Yue et al., 2008; Cheng et al., 2009; Thimmaiah et al., 2009; Hellebust et al., 2010; Sun et al., 2014; Hayes, 2014; Sowlat et al., 2016). The approach of using real-time gaseous pollutant data in receptor models may provide a small number of source factors and may not be able to identify some specific sources (e.g., road dust, secondary organic aerosol, biogenic) and distinguish different industry-related sources (e.g., metallurgy, refinery, cement kiln) that may be important sources in air sheds. However, in the absence of chemical speciation information it can offer useful preliminary results highlighting potential major emission sources types that can affect air quality at a receptor location in urban or rural areas. In a recent study (Bari and Kindzierski, 2017a), we applied the PMF model followed by multiple linear regression (MLR) to investigate $PM_{2.5}$ sources in the City of Red Deer, Alberta using gaseous pollutant data. In this present study, we characterized air quality in Hinton and investigated sources of $PM_{2.5}$ using PMF and available real-time continuous air monitoring data from November 2013 to February 2016 with an objective to identify local and potential long-range sources of $PM_{2.5}$.

2. Methodology

2.1. Ambient measurements of air pollutants

Alberta is oil and natural gas-rich and the fourth largest province located in western Canada. It has well-established conventional oil and gas extraction, refining and upgrading activities (Supplemental Information-SI, Fig. S1b) in addition to unconventional oil sands development in the northeast area of the province. Hinton is located 81 km northeast of Jasper National Park in the Rocky Mountains and about 284 km west of Alberta's capital city, Edmonton. Hinton is also located within the edge of established oil and gas extraction activities (Fig. S1b) and within the Alberta Energy Regulator 'Drayton Valley Field Centre' (Fig. S1c). During 2014, more than 5 million m^3 of oil and $3.5(10^3)$ million m^3 of solution gas was produced in the Drayton Valley Field Centre region where Hinton is located (AER, 2016).

As part of Environment Canada's NAPS initiatives, the West Central Airshed Society (WCAS, http://www.wcas.ca) has been responsible for regional air quality monitoring and providing results to Alberta Environment and Parks in west central Alberta. The WCAS airshed zone is approximately 46,000 km^2 and spans from the western boundary of Edmonton city limits to the British Columbia border (Fig. 1a). The topographical map of the town of Hinton and immediate surrounding area is shown in Fig. S2. Hinton has a humid, subarctic continental climate with wide fluctuations in temperatures e.g., long cold winters and short, cool summers. Seasonal average temperatures typically vary from −8.9 °C in January to 15 °C in July and the average annual precipitation is in terms of rain 45 cm and snow 168 cm (www.hinton.ca). Early morning ground-based temperature inversions are common throughout the whole year in Alberta with deeper and stronger inversions observed during winter months (Myrick et al., 1994), thus limiting the dispersion of air pollutants and potentially increasing pollutants levels in winter.

The study was performed using historical air quality data collected from Hinton air monitoring station (AMS) (53.4273011° N, 117.544067° W) for the period of January 2011–February 2016 (Fig. 1b). The station is located to the northeast of Hinton near busy roadways (within 100 m East River Road and to the northwest Willow Creek Road). These roadways are influenced by transportation of heavy haul trucks. There is a parking lot and a gas station (Fas Gas) located within 30 m south of the monitoring station, where heavy trucks park and idle in the morning hours (Greg Swain, personal communication). A small asphalt paving plant (Hinton Batch Plant-Border Paving Ltd.) is located within 0.5 km northwest of Hinton AMS and an adjacent parking lot exists that is mostly used for haul trucks. Highway 16 (Yellowhead Highway) is a major east-west transportation route from Manitoba to British Columbia and is located within 2 km from the monitoring station. National Pollutant Release Inventory (NPRI) (Environment Canada, 2016) reported annual releases of sulfur dioxide (SO_2), oxide of nitrogen (NO_X), and $PM_{2.5}$ to the air from major industrial facilities within 50 km surrounding the Hinton AMS is shown in Table S2. Hourly concentration data for criteria air pollutants i.e., nitric oxide (NO), nitrogen dioxide (NO_2), NO_X, SO_2, ozone (O_3), total reduced sulfur (TRS), and meteorological parameters were accessed via the Alberta Environment and Parks airdata warehouse (AEP, 2016). Hourly concentrations of TRS and $PM_{2.5}$ had been measured at Hinton AMS since 2004 and February 2010, respectively; while measurements of other pollutants (NO, NO_2, NO_X, SO_2, O_3) started from November 2013. Measurement instruments used for real-time air quality monitoring at Hinton AMS are shown in Table S3. Based on data availability of all criteria pollutants, the study period selected was from November 2013 to February 2016. Seasonal wind roses at Hinton AMS were generated for the selected study period (Fig. S3). Prevailing wind directions during winter and fall were strongly aligned with the valley from the south-southwest blowing 71% and 78% of the time, respectively with minor contribution from the northeast representing 18% of the time during fall.

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