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Twelve-year trends in ambient concentrations of volatile organic compounds in a community of the Alberta Oil Sands Region, Canada

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ABSTRACT

Environmental exposure to volatile organic compounds (VOCs) in ambient air is one of a number of concerns that the First Nation Community of Fort McKay, Alberta has related to development of Canada's oil sands. An in-depth investigation of trends in ambient air VOC levels in Fort McKay was undertaken to better understand the role and possible significance of emissions from Alberta's oil sands development. A non-parametric trend detection method was used to investigate trends in emissions and ambient VOC concentrations over a 12-year (2001 − 2012) period. Relationships between ambient VOC concentrations and production indicators of oil sands operations around Fort McKay were also examined. A weak upward trend (significant at 90% confidence level) was found for ambient concentrations of total VOCs based on sixteen detected species with an annual increase of 0.64 μg/m^3 (7.2%) per year (7.7 μg/m^3 increase per decade). Indicators of production (i.e., annual bitumen production and mined oil sands quantities) were correlated with ambient total VOC concentrations. Only one of 29 VOC species evaluated (1-butene) showed a statistically significant upward trend ($p = 0.05$). Observed geometric (arithmetic) mean and maximum ambient concentrations of selected VOCs of public health concern for most recent three years of the study period (2010 − 2012) were below chronic and acute health risk screening criteria of the U.S. Agency for Toxic Substances and Disease Registry and U.S. Environmental Protection Agency. Thirty-two VOCs are recommended for tracking in future air quality investigations in the community to better understand whether changes are occurring over time in relation to oil sands development activities and to inform policy makers about whether or not these changes warrant additional attention.

1. Introduction

Volatile organic compounds (VOCs) are a complex group of carbon-based organic chemicals that have high vapor pressure and are therefore emitted as gases from certain solids or liquids into the surrounding air at ambient temperatures. A number of studies suggest an association between ambient air exposure to certain VOCs and potential chronic and acute health outcomes such as asthma and respiratory symptoms (Otto et al., 1992; Delfino et al., 2003; Wichmann et al., 2009). Some VOC species (e.g., benzene) have been classified as carcinogens (IARC, 2015) and toxic as defined under the Canadian Environmental Protection Act (CEPA, 1999), and the United States Agency for Toxic Substances and Disease Registry (ATSDR, 2011). These classifications originate from animal toxicology studies or from epidemiologic studies in occupational settings. These are settings where exposure concentrations and duration of exposure are much greater than what would occur in community settings (Kindzierski, 2000).

There has been an increasing interest at the national and international level regarding the potential environmental and health impacts related to oil sand development in northeastern Alberta. Alberta's oil sands are the third largest reservoir of crude oil in the world with proven oil reserves of 170 billion barrels, consisting of bitum en (about 168 billion barrels) and conventional crude oil (1.7 billion barrels) after Venezuela and Saudi Arabia, covering an area of 142,200 km^2 in the Athabasca, Cold Lake and Peace River regions (Government of Alberta, 2014, Fig. 1). Earlier projections had oil sands production increasing from the present-day level of 1.98 million barrels/day (2013) to 3.7 million barrels/day by 2020 and 5.2 million barrels/day by 2030 (CERI, 2014); however the current price of oil i.e. less than $40 US per barrel makes this projection unlikely.

VOCs are ubiquitous in ambient air and are emitted from a wide range of natural (e.g., vegetation, soil, forest fires) and anthropogenic sources, including traffic, petroleum refining, storage and distribution of petroleum products, combustion and evaporation processes associated with industrial sources, solvent use and other industrial processes (Scheff et al., 1989; Doskey et al., 1992; Watson et al., 2001; Chen et al., 2005; Liu et al., 2008). In the Athabasca Oil Sands Region (AOSR) of Alberta, tailings ponds have generally been considered the primary source of VOC emissions either via volatilization at tailings inlets or pond surfaces of compounds discharged directly into the ponds or as a result of in-pond biodegradation of hydrocarbons by resident aerobic

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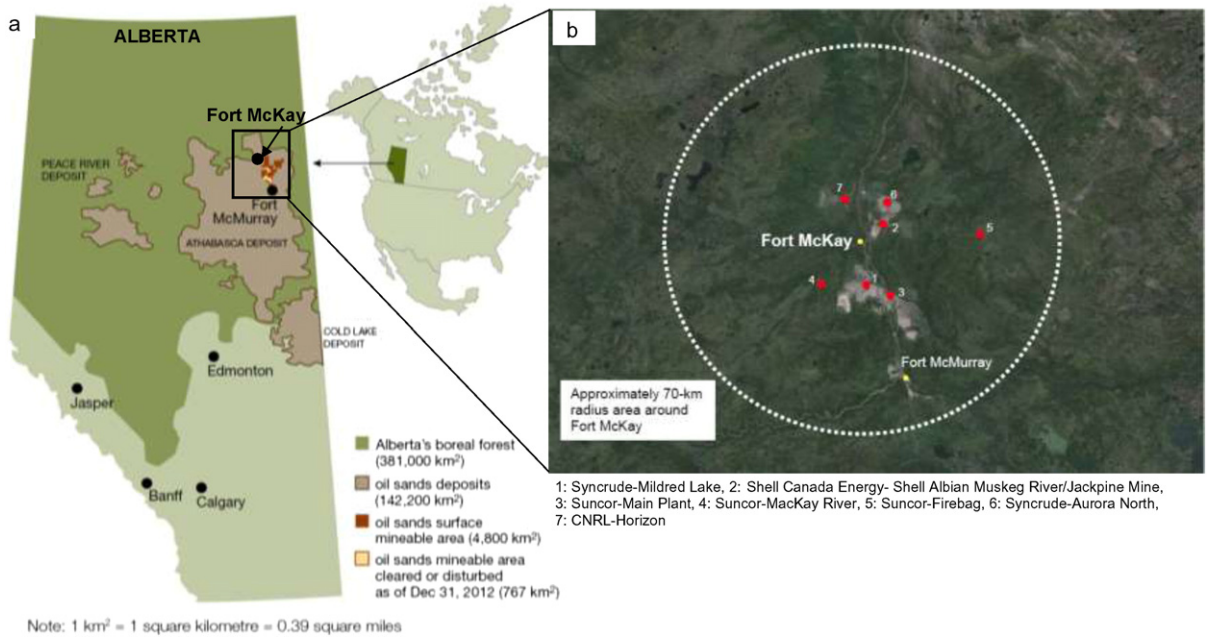

Fig. 1. a) Location of Fort McKay in the AOSR (source: Government of Alberta, 2014) and b) reported NPRI emission points for VOCs from oil sands and heavy oil facilities within 70-km radius area around Fort McKay in northeast Alberta.

and anaerobic microbiota and subsequent volatilization of these biodegradation products (Timoney and Lee, 2009; Small et al., 2015). A recent evaluation of VOC emissions from oil sands development (CEMA, 2012) categorized and identified regional VOC emissions as coming from stack, fugitive plant emissions, mines, tailings ponds and non-industrial emissions with plant fugitive and tailings ponds being the most significant sources.

A tailings pond contains the residue or tails after bitumen is extracted from the oil sands, and consists of process water, sands, silts, clays, residual bitumen (1–5%) and associated chemicals e.g., from paraffinic or naphthenic solvents used in the extraction process to separate bitumen from water (Allen, 2008; Timoney and Lee, 2009; Oil Sands Magazine, 2015). According to Environment Canada's National Pollution Release Inventory (NPRI), major anthropogenic emission sources of VOCs during 2013 in Alberta were the upstream petroleum industry (443,250 tonnes), downstream petroleum industry (9259 tonnes), light and heavy-duty diesel and gasoline vehicles and trucks (32,344 tonnes), general solvent use (23,575 tonnes), and surface coatings (Environment Canada, 2015).

Several studies have been carried out in Europe (Thijsse et al., 1999; Rehwagen et al., 2003; Hakola et al., 2006; Dollard et al., 2007; Sauvage et al., 2009; von Schneidemesser et al., 2010) and U.S. cities (Fortin et al., 2005; Stemmler et al., 2005; Warneke et al., 2012) to investigate trends in ambient VOC concentrations. Most of these studies analyzed trends in urban vehicle-related VOC emissions and ambient air quality. Bunch et al. (2014) and Vinciguerra et al. (2015) recently examined ambient VOC trends to assess the influence of emissions from shale gas operations in Texas and Maryland. Relatively short atmospheric lifetime of most VOCs, i.e. minutes to days, as a result of tropospheric oxidation or photolysis reactions (Atkinson, 2000) means that ambient VOC levels will be very local in character and related to local, near-field VOC emission sources.

In the AOSR of Alberta, limited studies have been conducted to find out the influence of oil sands development on ambient VOC levels. CEMA (2007) investigated ambient VOC levels and sources for the time period of 2004–2005. Simpson et al. (2010) characterized 76 speciated C_2–C_{10} VOC species from Alberta oil sands surface mining operations during summer 2008 using boundary layer whole air sampling. Percey (2013) reported ambient VOC concentrations during 2012 in all community and industry stations in the AOSR. In this study, we made an in-depth investigation of 12-year trends (2001–2012), monthly and annual concentration profiles of VOCs in the AOSR community of Fort McKay in order to better understand the influence of emissions from Alberta's oil sands development and whether concentrations of VOCs have changed over this time period in relation to industrial and other development activities.

2. Methodology

2.1. Study area

The Wood Buffalo Environmental Association (WBEA, www.wbea.org) located in Fort McMurray has until recently been responsible for regional air quality monitoring in the oil sands region. In this study, WBEA's Bertha Ganter-Fort McKay air monitoring station (AMS) was used for investigation of VOC trends. Fort McKay (area 8.2 km^2, 57°11′20.9″N, 111°38′25.9″W, elevation ~270 m) is a First Nations community (~850 community members with ~550 residing in the community) located along the Athabasca River (Fig. 1a). The Bertha Ganter-Fort McKay AMS is located near the northwest corner of their water treatment plant property on the north end of the community. A windrose for Fort McKay for the 12-year period (2001–2012) is shown in Fig. S1 using data from CASA (2014). Winds from the north and south predominate and are aligned with Athabasca River valley. The community is within 25 km of several active oil sands development (Fig. 1b), three of which have bitumen upgraders. The closest tailings pond is within 5 km of the community. This community is important in terms of the real influence that these developments have on air quality in the region. As the closest location where people live with respect to active and planned oil sands development that have large open pit (surface) mines, and petroleum upgrading and processing facilities, it is important to understand to what extent oil sands development may be impacting community air quality.

National Pollutant Release Inventory (NPRI) report annual releases of VOCs from Canadian industrial facilities/operations (Environment Canada, 2015). Releases of total VOCs, BTEX (benzene, toluene, ethylbenzene, xylenes) and hexane to air from oil sands and heavy oil facilities within a 70-km radius of the Fort McKay station (Fig. 1b) are