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Fifteen-year trends in criteria air pollutants in oil sands communities of Alberta, Canada

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ABSTRACT

An investigation of ambient air quality was undertaken at three communities within the Athabasca Oil Sands Region (AOSR) of Alberta, Canada (Fort McKay, Fort McMurray, and Fort Chipewyan). Daily and seasonal patterns and 15-year trends were investigated for several criteria air pollutants over the period of 1998 to 2012. A parametric trend detection method using percentiles from frequency distributions of 1 h concentrations for a pollutant during each year was used. Variables representing 50th, 65th, 80th, 90th, 95th and 98th percentile concentrations each year were identified from frequency distributions and used for trend analysis. Small increasing concentration trends were observed for nitrogen dioxide (<1 ppb/year) at Fort McKay and Fort McMurray over the period consistent with increasing emissions of oxides of nitrogen (ca. 1000 tons/year) from industrial developments. Emissions from all oil sands facilities appear to be contributing to the trend at Fort McKay, whereas both emissions from within the community (vehicles and commercial) and oil sands facility emissions appear to be contributing to the trend at Fort McMurray. Sulfur dioxide (SO_2) emissions from industrial developments in the AOSR were unchanged during the period (101,000 ± 7000 tons/year; mean ± standard deviation) and no meaningful trends were judged to be occurring at all community stations. No meaningful trends occurred for ozone and fine particulate matter ($PM_{2.5}$) at all community stations and carbon monoxide at one station in Fort McMurray. Air quality in Fort Chipewyan was much better and quite separate in terms of absence of factors influencing criteria air pollutant concentrations at the other community stations.

1. Introduction

There has been a growing interest at the provincial, national, and international level about environmental impacts related to oil sands development in northeastern Alberta. Alberta's oil sands are the third largest reservoir of crude oil in the world after Venezuela and Saudi Arabia, which underlie 140,200 km^2 of land in the Athabasca, Cold Lake and Peace River areas in northern Alberta (AESRD, 2012). In 2010, Alberta's total oil reserves were about 12% of global oil reserves, i.e., 170.8 billion barrels of which crude bitumen reserves account for 169.3 billion barrels and about 80% of the reserves is considered recoverable by in-situ methods and 20% by surface mining (Alberta Energy, 2011). With increasing oil prices, planned expansion of oil sands facilities is estimated to increase production from 1.5 million barrels/day in 2010 to 3.7 million barrels/day by 2025 (CAPP, 2011).

Potential exposure to ambient air pollution has been associated with effects on the respiratory and cardiovascular systems, asthma, and mortality (Pope and Dockery, 2006; Schwartz, 1993; Weichenthal et al., 2014). A current belief is that air quality in the oil sands region is poor and it is adversely affected by oil sands development (Timoney and Lee, 2009; Weinhold, 2011). However, several in-depth investigations (Kindzierski et al., 2009; RSC, 2010) have demonstrated that ambient air quality monitoring data for the region show minimal air quality impacts from oil sands development.

Ambient air quality depends on a number of factors, including various natural (e.g., forest fire) and anthropogenic emission sources in a given area (e.g., traffic exhaust, industrial and commercial activities, domestic heating), meteorological conditions (e.g., inversions with poor vertical mixing), and other atmospheric and topographical factors affecting removal of pollutants from the atmosphere. It is important to monitor and evaluate ambient air quality in order to characterize and understand the state of air quality. However, this information is not sufficient for understanding changes in air quality over time. Trend analysis of ambient air quality is another important aspect in characterizing the state of air quality. The usefulness of trend analysis depends on magnitude of emissions of interest, quality and length of record of monitoring data, capabilities of monitoring instruments (i.e., detection limit, accuracy, and precision), and relative magnitudes of emissions- and weather-driven variations in ambient concentrations (Blanchard, 1999). Estimation of emission-related trends requires statistical models

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that account for sources of variability underlying the pollutants, such as seasonal changes and meteorology (Lynch et al., 2000; Porter et al., 2001).

Recent studies of time–activity patterns have shown that Canadian adults spend an average of 69% of their time in indoor residential environments with an increased amount of time spent indoors at home during winter (1 h 11 min on average) compared to summer (Matz et al., 2014; Wheeler et al., 2011). Several studies have been undertaken in Fort McKay, Alberta during the past 10 years to examine indoor/outdoor relationships of sulfur dioxide (SO_2) and volatile organic compounds (VOCs), and personal exposure to VOCs (Hoeksema and Kindzierski, 2010; Kindzierski and Miyagawa, 2007; Kindzierski and Ranganathan, 2006). Ambient SO_2 is a good marker for atmospheric emissions of activities involving upgrading and processing of fossil fuels containing sulfur. These studies have reported that proximity of Fort McKay to oil sands development activity has not resulted in increased levels of SO_2 or VOCs outside and inside of Fort McKay homes. In addition, indoor concentrations of these air pollutants were similar to levels seen elsewhere in Canada, United States, and Europe. Personal VOC exposure levels were found to be strongly correlated with levels measured inside residences, similar to findings of other personal exposure studies in industrialized areas of North America (TCEQ, 2010).

Comparatively few studies have been carried out to find out the impacts on regional ambient air quality from Alberta's oil sands development activities. Barrie (1980) measured ambient concentrations of gaseous and particulate sulfur and elements of PM at Mildred Lake 10 km NNW of an isolated oil sands extraction power plant on the west bank of the Athabasca River. Kelly et al. (2009, 2010) investigated contributions of oil sands development for polycyclic aromatic hydrocarbons (PAH) and 13 elements to the Athabasca River and its tributaries. Simpson et al. (2010) characterized trace gas emissions from Alberta oil sands surface mining operations. Using satellite remote sensing observations, McLinden et al. (2014, 2012) investigated nitrogen dioxide (NO_2) and SO_2 air column concentrations over the AOSR. Cho et al. (2012a,b) studied emission source sensitivity for ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$) due to oil sands development in the AOSR using source apportionment modeling. Other researchers (Hoeksema et al., 2010; Jain and Bell, 2010) performed numerous regulatory dispersion modeling to assess effects of oil sands development on air quality in the AOSR. Kurek et al. (2013) inferred historical (50-year) PAH deposition in lake sediments to provide ecological context about oil sands development affecting lake ecosystems in the AOSR. Percy (2013) reported ambient air quality during 2012 and linkage to ecosystems in the AOSR. In recent studies, wintertime atmospheric deposition of metals and PAH using bulk deposition sampling (Bari et al., 2014) and PAH deposition using snowpack sampling (Cho et al., 2014) in the AOSR were reported. However, a detailed investigation of criteria air pollutants in the oil sands region is needed to get a better understanding of air quality impacts from oil sands development.

In this study, we made an in-depth investigation of 15-year trends, diurnal hourly and annual average concentration profiles, and exceedances of provincial ambient air quality objectives for criteria air pollutants continuously measured at three communities within the AOSR. Criteria air pollutants investigated were oxides of nitrogen (NO, NO_2, NO_x), O_3, $PM_{2.5}$, SO_2, total hydrocarbons (THC), total reduced sulfur (TRS) and carbon monoxide (CO). THC is normally used as a surrogate volatile hydrocarbon measurement in Alberta to indicate the presence of atmospheric emissions from industrial activities. THC primarily consists of methane; however ethane and other aliphatic and aromatic hydrocarbons are emitted from processing, storage, use and combustion of petroleum, natural gas and coal in Alberta. The objective of this study was to establish, whether and the extent to which, concentrations of air pollutants have changed over the time period in relation to industrial and other development activity.

2. Methodology

2.1. Study areas

Data from four monitoring stations (one in Fort McKay, 2 in Fort McMurray and one in Fort Chipewyan) were used for the study (Fig. 1a). Fort McKay (57° 11′ 20.9″ N, 111° 38′ 25.9″ W, elevation ~270 m) is a First Nations settlement of less than 1000 people along the Athabasca River with a monitoring station located near the northwest corner of their water treatment plant property. The settlement is within 25 km of several major active oil sands development e.g., bitumen surface mine and upgrading operations. This community is important in terms of the real influence that these developments have on air quality in the region. It is the closest location where a community of people lives with respect to active and planned oil sands development that has large open pit (surface) mines, and petroleum upgrading and processing facilities. Fort McMurray is 435 km northeast of Edmonton on Highway 63, about 60 km west of the Saskatchewan border, nestled in the boreal forest at the confluence of the Athabasca River and the Clearwater River. It is the largest community (72,944 in 2012 Municipal Census) in the Regional Municipality of Wood Buffalo and it is located more than 30 km south of the closest major oil sands operations. Two selected monitoring stations in Fort McMurray are Patricia McInnes (56° 45′ 8.3″ N, 111° 28′ 34.1″ W, elevation 361 m) and Athabasca Valley (56° 43′ 58.0″ N, 111° 23′ 24.6″ W, elevation 251 m). Fort Chipewyan (58° 42′ 30.1″ N, 111° 10′ 35″ W, elevation 220 m) is another First Nations settlement and a hamlet in northern Alberta within the Regional Municipality of Wood Buffalo. With an area of 10.24 km^2 and population of less than 1000, it is located on the western tip of Lake Athabasca, adjacent to Wood Buffalo National Park, approximately 223 km north of Fort McMurray and it is more than 150 km downstream with respect to the Athabasca River of any major active oil sands surface mining operations. National Pollutant Release Inventory (NPRI) reports annual releases of oxides of nitrogen (NO_x), SO_2 and TRS from Canadian industrial facilities/operations (Environment Canada, 2014). NO_x, SO_2 and TRS releases from industrial facilities/operations within a 70-km radius of the Fort McKay station (Fig. 1) are summarized in Tables S2, S3 and S4, respectively. Since 2002 NO_x releases have increased ca. 1000 tons/year, while SO_2 emissions have shown no trend, and average releases of 101,000 $\pm$ 7000 tons/year (mean $\pm$ standard deviation) (Fig. 2). Release data for TRS only go back to 2007 (Table S4) and total TRS emissions increased until 2009 and then decreased thereafter. NPRI quantities do not account for small emission sources, such as small compressors and generators, and emissions from private/commercial vehicles and non-oil sands commercial operations in the AOSR.

2.2. Data analysis

The Wood Buffalo Environmental Association (WBEA) located in Fort McMurray has been responsible for regional air quality monitoring in oil sands region (refer to Table S1 for instrumentation used). Hourly concentration data for NO, NO_2, NO_x, SO_2, $PM_{2.5}$, and O_3 (4 stations), THC and TRS (3 stations), and CO (1 station) were accessed for a 15-year period (1998 to 2012) via the Clean Air Strategic Alliance (CASA, 2014) data warehouse. These data were obtained in temporal order of year, month, day, and hour. A cut-off criterion of 80% completeness was used as an initial screening step to establish whether to include an annual data set in trend analysis. This criterion represents ~7000 hourly values for an annual data set and was judged more than adequate for purposes of this study; in addition it is a criterion similar to that used by others (Blanchard, 1999). The general approach for detecting air quality trends over time is to begin with valid data sets, and then select response variable (metrics) — such as means, medians, maxima, minima, selected percentiles, etc., select appropriate time periods to investigate (e.g., season, episode, annual, etc.), apply