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Regional Distributions of Atmospheric Emission, Concentration, and Deposition of Particulate Elements in the Canadian Athabasca Oil Sands Region

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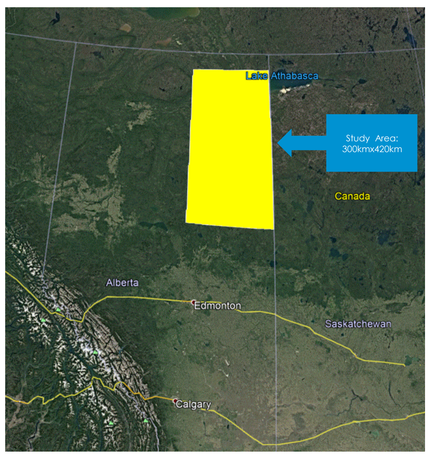
Background Information

- Elements (mostly metals/metalloids) are associated with particulate matter, and have both positive and negative impacts on humans. Some elements such as Cu, Fe, and Zn are essential for human body, other elements such as Cd, Pb, and Hg are toxic, even at low exposure levels. USEPA recognized 13 elements (Sb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Tl, and Zn) as priority pollutant.
- Surface mining in the Athabasca Oil Sands Region (AOSR) of northern Alberta, Canada is a source of airborne particulate elements. The Oil Sands Monitoring program initiated in 2011 by the Governments of Canada and Province of Alberta is aimed at studying the cumulative effects of oil sands development through environmental monitoring and research of contaminants including the major and trace elements.
- Goals: characterize ambient concentration and atmospheric deposition of the elements; conduct source apportionment analysis and quantify regional emissions; and assess the impact of oil sands activities to the total atmospheric deposition.
- Challenges: only ambient concentration data and only at four sites are available; no precipitation chemistry measurement; no existing emission inventory available.

Methodology for emission inventory development

- Develop an emission inventory for elements in $PM_{2.5}$ and $PM_{2.5-10}$ by speciating the Air Emissions Inventory for particulate matter based on the USEPA speciation profiles in SPECIATE v4.5 database.
- Evaluate the developed emission inventory by using this inventory as input to the CALPUFF dispersion model and simulate elements concentrations in both $PM_{2.5}$ and $PM_{2.5-10}$, and then compare with measurements collected at three sites during 2016-2017.



Results from emission inventory development

- For the summed emissions of elements in $PM_{2.5}$, the top two source categories were O Sources (1741 tonnes/year, 16.3% of the total $PM_{2.5}$) and Non-OS Dust (470 tonnes/year, 4.4%). The summed emissions from the remaining seven sectors were approximately 100 tonnes/year and comprised ~1% of the total $PM_{2.5}$ emissions.
- The top two source categories for summed elements in $PM_{2.5-10}$ were OS Sources (6088 tonnes/year, 21.5% of the total $PM_{2.5-10}$) and Non-OS Dust (2489 tonnes/year, 8.8%). The summed emissions from the rest of the seven sectors were approximately 210 tonnes/year and comprised ~0.7% of the total $PM_{2.5-10}$ emissions.

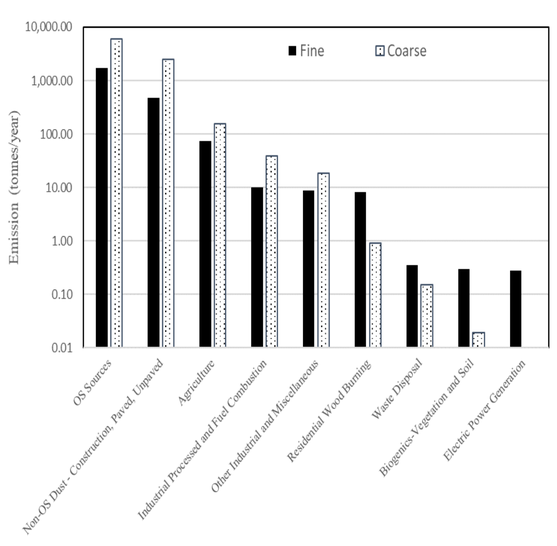


Figure. Regional total emissions of the sum of 29 elements in $PM_{2.5}$ and $PM_{2.5-10}$ from nine source sectors

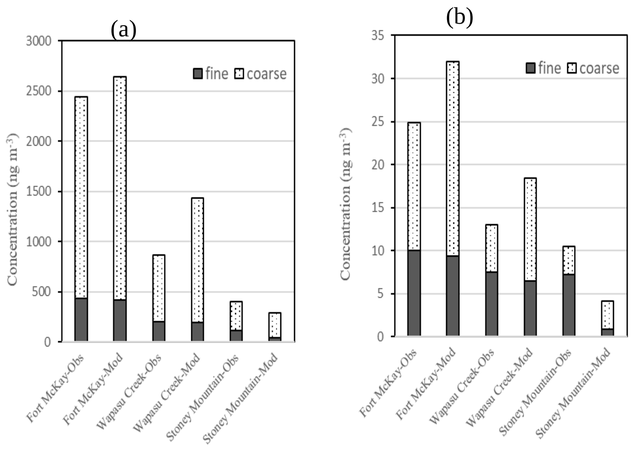


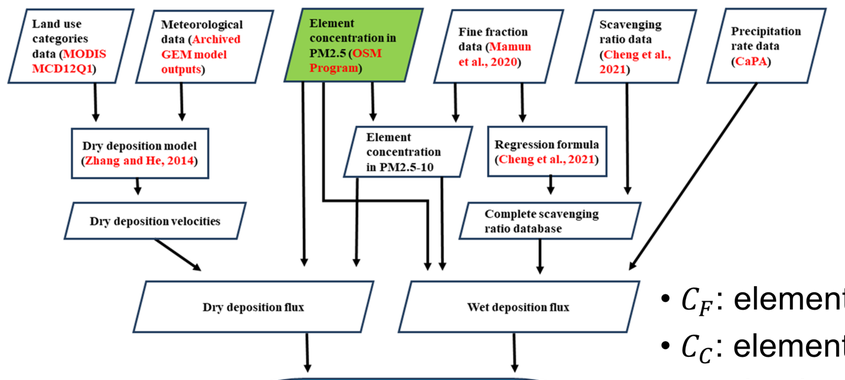
Figure. Comparison of observed (Obs) and modeled (Mod) concentrations at three monitoring sites: (a) sum of 24 fine elements and 9 coarse elements, and (b) sum of 10 fine priority elements and 2 coarse priority elements

No systematic positive or negative model bias: Modeled PM_{10} concentrations of all elements were very close to the measurements at an industrial site with the highest ambient concentration, overestimated by 65% at another industrial site with moderate ambient concentration, and underestimated by 27% at a remote site with very low ambient concentration.

Yang et al., 2023. *Environ. Res.*, 220, 115223

Methodology for deposition calculation

Flux calculation framework

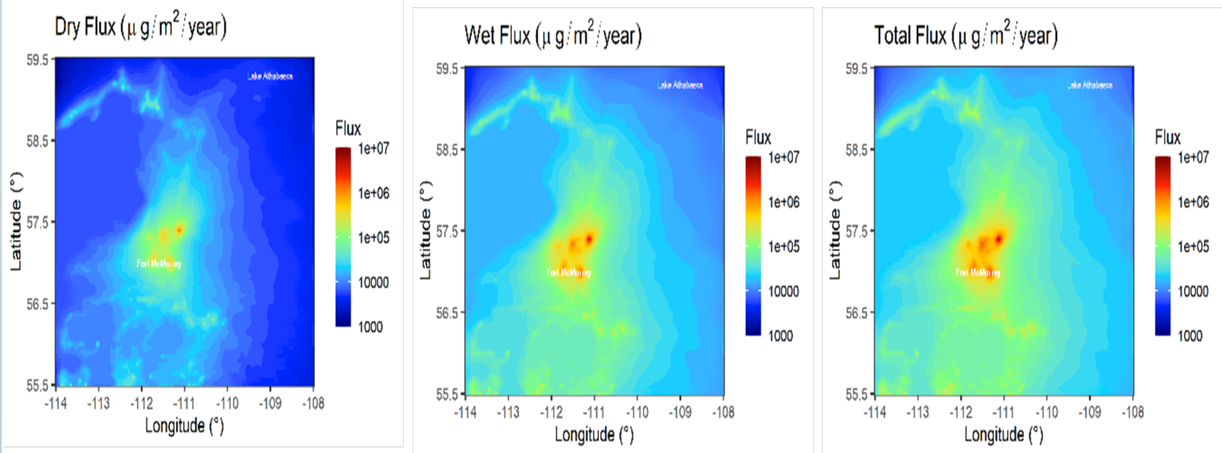


Dry dep: $F_d = C_F v_F + C_C\, v_c$

Wet dep: $F_w = C_F WP + C_C\, WP$

- C_F: element concentration in $PM_{2.5}$
- C_C: element concentration in $PM_{2.5-10}$
- v_F: dry deposition velocity of $PM_{2.5}$
- v_C: dry deposition velocity of $PM_{2.5-10}$
- W: element scavenging ratio
- P: precipitation rate

Results from deposition study



- Domain-average dry and wet fluxes for total elements were 15.7 and 45.2 mg/m^2/year (or 26% and 74%), respectively
- Element fluxes peaked at the center of the domain and decreased outward; Fluxes varied up to 3 orders of magnitude across the domain
- Spatial patterns of the dry, wet, and total deposition were similar

Mamun et al., 2023. Environ. Pollut., 898, 165519

Methodology for investigating contributions of the oil sands sources to the ambient concentrations

Category	$PM_{2.5}$		$PM_{2.5-10}$	
	non-point	point	non-point	point
Oil Sands mines, Off-road Fleet	15.2%	0%	0.4%	0%
Oil Sands mines, Unpaved road dust	60.3%	0%	66.6%	0%
Others	24.5%	100%	33.1%	100%

- Group emission sources into oil industrial activities and other sources, and run the dispersion model for sensitivity tests: 3 model runs for $PM_{2.5}$ and 2 model runs for $PM_{2.5-10}$
- Mass balance is assessed based on model out of ambient

Results from source attribution model sensitivity study

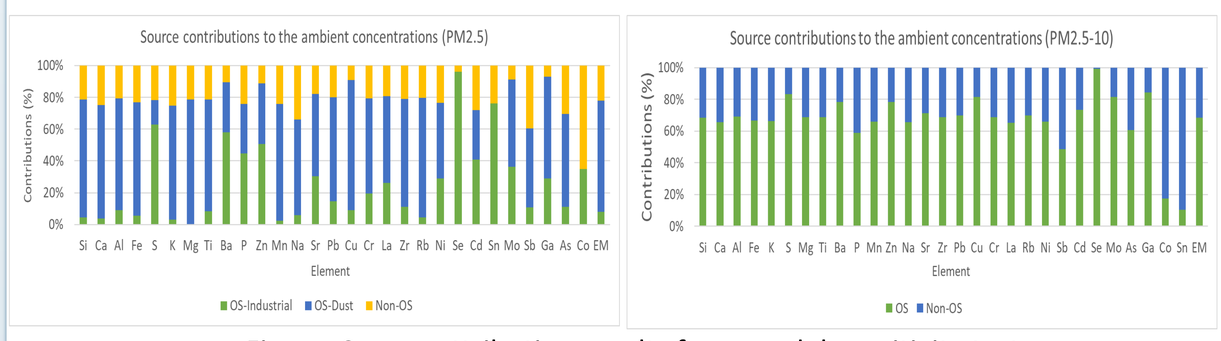


Figure. Source attribution results from model sensitivity tests

- Fine mode
  - OS vs Non-OS
    - For all elements together, 78% of the ambient mass concentrations were from the oil sands related sources (OS-Industrial and OS-Dust)
    - Except for Co, all elements primarily came from the oil sands related sources; e.g., Se (96%), Ga (93%), Mo (91%)
  - OS-Industrial vs OS-Dust
    - Aside from S, Ba, P, Zn, Cd, Se, Co, and Sn, for all elements OS-Dust source was dominant
- Coarse mode
  - OS vs Non-OS
    - For all elements together, 68% of the ambient mass concentrations were from the oil sands related sources
    - Except for Sb, Co, and Sn, all elements primarily came from the oil sands related sources, e.g., Se (99%), Ga (84%), S (83%)

Yang et al., 2023. . Sci. Total Environ., 898, 165519