Top-down aircraft-based measurements of emissions of particles from surface mining facilities in the Alberta oil sands region, Canada

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Surface mining in the oil sands regions represents a large source of fugitive dust. Quantification of fugitive dust particle emissions into the atmosphere is difficult due to technical challenges, especially for major industrial facilities that cover large geographic areas. Accurate assessments of emissions from large scale industrial developments are required both for regulatory reporting and for scientific studies of the impact of emissions on ecosystems. The Alberta oil sands region has the third largest fossil fuel deposit in the world. Half of the current oil production from the oil sands is from open surface mining facilities. Each facility covers an area of up to 400 km^2, and contains complex operations related to mining, transportation, separation, upgrading and waste tailing storage, many of which have associated particle emissions. Particulate matter (PM) emissions are required to be reported to emissions inventories, and real-world measurements of PM emissions can serve as an important validation of inventory estimates. An aircraft-based measurement study in summer 2013 that was designed to measure air pollutants emitted from the oil sands surface mining facilities, determine how far they are transported, and understand how they are chemically converted in the atmosphere was carried out in support of The Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring (JOSM, 2012). Measurements of particles from 0.06 to 20 μm diameters were made at 1 second time resolution using two particle sizing instruments including the Ultra-High Sensitivity Aerosol Spectrometer (UHSAS) and the Forward Scattering Spectrometer Probe (FSSP-300).

The particle number size distributions from both the UHSAS and FSSP300 instruments allowed integrated particle volumes to be determined at a 1-s resolution. To derive the mass size distribution, a varying density was applied to different particle sizes, from 1.5 g/cm^3 for particles <1 μm diameter (based on concurrent aerosol mass spectrometer measurements), to 2.5 g/cm^3 for particles > 2.5 μm (using the known mineral dust composition for the region). To quantify particle mass emission rates from surface mining facilities, a top-down approach was used, with specifically designed flight patterns that created virtual boxes of vertically stacked flight tracks around the facilities. Integrated mass fluxes across the box walls and ceilings were determined from the measurement results, from which the emission rates of the measured pollutant species could be derived. This approach forms the basis of the Top-down Emission Rate Retrieval Algorithm (TERRA) that was developed to determine mass fluxes into and out of the virtual box (Gordon et al., 2015).

For the virtual box around a surface mining facility, TERRA calculates the individual terms in the following equation to derive the emission rate:

$$E = E_H + E_{HT} + E_V + E_{VT} + E_{VD} - E_M$$

where E is the emission rate, E_H is the horizontal advection flux term, E_{HT} is the horizontal turbulent flux term, E_V is the vertical advection flux term, E_{VT} is the vertical turbulent flux term, E_{VD} is the dry deposition, E_M is the mass change with time. Each term can be determined from air mass density, pollutant mixing ratio, wind speed, estimated diffusion coefficients, and dry deposition velocity (Gordon et al., 2015). Using the airborne measurements, the emission rates for a pollutant can be derived within uncertainties of 20% for both stack plume and surface emissions (Gordon et al., 2015).

For the 6 major surface mining operations in the Alberta oil sands region, the emission rates for PM_1, $PM_{2.5}$, and PM_{10} were obtained by applying the TERRA algorithm to the integrated mass using the UHSAS and FSSP300 instruments. For each facility, the observed atmospheric PM_1 mass concentrations were clearly associated with plumes from the stacks, whereas PM_{10} mass concentrations were clearly associated with mining and transportation activities. The derived emission rates of $PM_{2.5}$ and PM_{10} will be compared with facility reported emission rates. The measurement-based top-down emission rates from the present study for oil sands facilities serves as an example of how airborne measurements can be used as an independent source of emission estimates.

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