Characteristics of Tailpipe and Non-Tailpipe Particulate Matter in Toronto

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BACKGROUND
- Twenty-four-hour integrated filter-based chemical speciation data of PM2.5 collected over the last 14 years in Toronto were utilized to
  - Identify the long-term trends of PM2.5 sources in the metropolitan area
  - Investigate factors driving change in the trends
  - Assess the source-specific health effects of PM2.5
- Hourly PM2.5 chemical speciation data simultaneously measured at multiple near-road locations were examined to
  - Estimate the contribution of local traffic-related sources on PM2.5
  - Characterize decay gradients of traffic-related PM2.5 under cold winter temperatures

METHODOLOGY

Site Description
- Downtown Toronto (NR-TOR-2)
  - 24-hour integrated PM2.5 chemical speciation data: March 1, 2004 - April 4, 2017
  - Hourly PM2.5 chemical speciation data: May 10 - Aug. 31, 2016
  - Traffic density: 15 m from the 4-lane arterial road, ~16,000 vehicles/day
- Highway 401 (NR-TOR-1)
  - Hourly PM2.5 chemical speciation data: May 10 - Aug. 31, 2016
  - Traffic density: 10 m from the edge of highway 401 ~410,000 vehicles/day
  - Wintertime hourly PM2.5 chemical speciation data: Feb 6 - Feb 27, 2017 (10 m vs. 150 m from highway 401)

Instrumentation
- 24-hr integrated PM2.5 filters collected by two samplers were analyzed by Ion Chromatography (IC), energy dispersive x-ray fluorescence (ED-XRF), acid digestion Inductively-Coupled Plasma Mass Spectrometry (ICPMS), and thermal optical reflectance (TOR)
- Hourly organics, sulphate, nitrate, and ammonium by Aerosol Chemical Speciation Monitor (ACSM, Aerodyne)
- Hourly trace elements by Xact Metals Monitor (Xact 625, Cooper Environ)
- Real-time gas- and particle-phase air pollutants: NOx, NOy, CO, SOx, Ultrafine Particles (UPP, FPMPS), Black Carbon (BC, AE33), PM2.5 (SHARP)
- Met data: Wind Speed, Wind Direction, Temperature, Relative Humidity

Data Analysis
- Receptor modeling: Positive Matrix Factorization (PMF, EPA PMF 5)
- Trend Analysis: Marine-Kendall test and Sen's slope
- Wind sector analysis
- Oxidative Potential (OP); Ascorbate Acid (AA) assay
  - Intrinsic PM redox activity: AA depletion rate normalized by PM mass

LONG-TERM TRENDS OF PM2.5 SOURCES
- Annual concentrations of PM2.5 and reconstructed chemical composition and annual, monthly and day-of-the-week patterns of NO2, SO2, UF and UP
  - The annual concentrations of PM2.5 in Toronto decreased by 34% between 2004 and 2016 with the decreases of local and regional air pollutants.

DECAY GRADIENTS IN WINTER
- Decay gradients of Tailpipe and Non-Tailpipe PM2.5 during downwind, upwind, and air stagnation conditions at 10 m and 150 m from highway 401
  - A very sharp decay gradient was observed for non-tailpipe PM2.5.
  - Winter stagnant air conditions further widened this traffic-influenced area to the point where concentrations were similar 10 m and 150 m away from the road, suggesting that the influence of the traffic emissions extended far beyond 150 m.

SUMMARY
- Improvements to vehicle technologies have led to an overall reduction in local tailpipe PM2.5 emissions with the reduction of traffic-related air pollutants.
- Non-tailpipe emissions mainly from brake wear and resuspension of road dust are emerging and contributing more PM2.5 than primary tailpipe emissions.
- Non-tailpipe emissions contributed a substantial fraction of redox-active trace metals.
- Traffic-related PM2.5 showed different degrees of inhomogeneity across the sites in Toronto. Tailpipe and non-tailpipe vehicle emissions are producing, as observed, 15% to 28% (29% to 49% during morning rush hour) of the PM2.5 observed near roads.
- Winter stagnant air can widen the near-road influenced area, and thus the extent of human exposure to related pollutants can vary with meteorology.
- Further studies are recommended to understand the implication of heavier vehicles adversely affecting non-tailpipe emissions and the relationship between exposure to non-tailpipe emissions and health outcomes.
- The effectiveness of mitigation strategies, such as road sweeping, trapping brake particles or regulations for the composition of brake pads, needs to be explored.

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Near-road Measurements

- Air pollutant measurements near roadways are heavily influenced by traffic.
- Quantifying the amount traffic contributes to these concentrations is challenging.

Background Subtraction Methods

Method 1: Site Differences

- Near-road pollutant concentrations occurring as a result of traffic were estimated based on differences between near-road and background station pairs (i.e., NR-VAN and BG-VAN, NR-TOR-1 and BG-TOR-1, and NR-TOR-2 and BG-TOR-2).

Method 2: Downwind/Upwind Differences

- For each near-road station, excess pollutant concentrations were determined based on differences between measurements taken downwind and upwind of the road.

Method 3: Baseline Inference

- Excess concentrations at each near-road station were approximated based on baseline inference using time-series analysis. This inferred baseline is intended to reasonably approximate concentrations measured at nearby background stations.

Effect of Meteorology on Local Concentrations

- Local traffic-related concentrations, as determined using Method 3, were compared with meteorological data from NR-TOR-1 and NR-VAN.
- Concentrations were normalized with respect to mean values for comparability amongst all pollutants.

Conclusions

- Local pollutant concentrations were up to six times higher when the monitoring station was directly downwind of the road, compared with the upwind case.
- Pollutant concentrations decreased by a factor of four with increasing wind speeds from 4 to 40 km hr⁻¹ (ε₂ = 0.5–0.6).
- Method 3 (baseline inference) was shown to reliably predict background concentrations (except PM₂.₅), whereas downwind/upwind analysis over-predicted the influence of traffic.

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