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Isotope Evidence Reveals Distinct Seasonal Patterns in Montréal's CO_2 and CH_4 Emissions

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Cities are central to climate change, yet urban greenhouse-gas inventories often cannot identify which sources dominate or how that mix shifts seasonally especially in cold climates where winter heating and atmospheric mixing strongly influence emissions. In Montréal, CH_4 and CO_2 come from sources like transport, building heating, natural-gas infrastructure, landfills (active and decommissioned), and wastewater, and these sources are difficult to distinguish from concentration data alone. We address this gap using chemical "fingerprints" from stable isotopes: $\delta^{13}C$-CO_2 and dual methane isotopes ($\delta^{13}C$-CH_4, $\delta^{2}H$-CH_4), which improve separation when carbon-isotope ranges overlap. From May 2024 to November 2025 (ongoing), we combined direct source sampling (vehicle tailpipe CO_2, heating-exhaust CO_2, and natural-gas network/leak samples) with mobile downwind plume sampling at four landfills (one active, three historic) and the wastewater treatment facility, plus high-frequency rooftop monitoring (50-55 m above ground) to capture city-wide variability. Source signals were extracted using Miller-Tans and Keeling-plot mixing, supported by regression diagnostics and a seasonal Bayesian mixing model (MixSIAR) with uncertainty propagation. Vehicle CO_2 clusters near -29.0±0.4‰, trending slightly more negative in winter. Heating-related natural-gas CO_2 is far more negative (-50.3±0.4‰), most negative in winter (-51.31±1.36‰) and spring (-49.85± 0.73‰) and less negative in warmer periods (-43.63±0.39‰ in summer; -41.49±0.32‰ in fall), indicating a stronger heating imprint in cold months. For CH_4, landfill emissions (-59.3±0.6‰ $\delta^{13}C$; -261.7±10.2‰ $\delta^{2}H$) are distinct from fugitive natural-gas emissions (NGFE -42.2±0.6‰; meter-point -40.7±1.8‰; $\delta^{2}H$ -216.5±0.8‰). Monthly atmospheric results suggest landfills and NGFE alternate as dominant CH_4 contributors with landfills generally dominating in warmer months, and NGFE in colder months. These results support municipal inventory verification and provide a replicable framework for improved urban emissions reporting and mitigation planning.