A network of EM27 FTS for urban measurements of X_{CO2}, X_{CH4}, and X_{CO} across the city of Toronto

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Motivation to monitor greenhouse gases in Toronto

- "Urban areas in North America are the primary source of anthropogenic carbon emissions, with cities responsible for a large proportion of direct emissions."[a]

- Toronto is the most populous city in Canada and the 4th most populous in North America.

- Toronto has set ambitious emissions reduction targets and aims to reach net-zero emissions by 2040.

https://www.researchgate.net/figure/Figure-1-The-Greater-Toronto-and-Hamilton-Area-GTHA-Metrolinx-2008-Traditional_fig1_258174028 [accessed 18 Jul, 2019]

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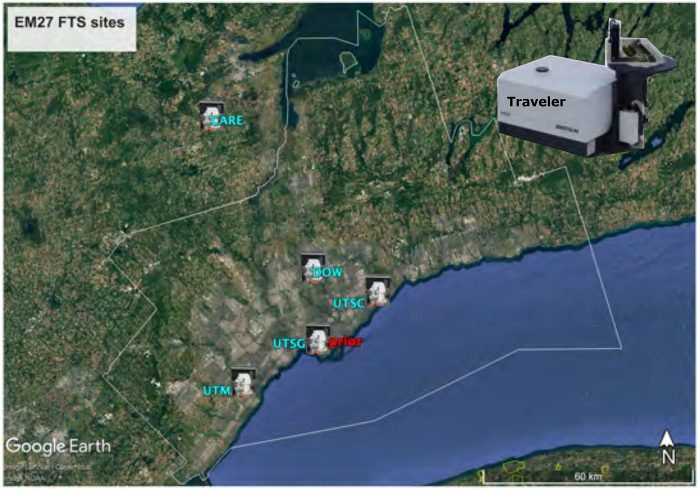
[a] K. R. Gurney et al. (2018). *Chapter 4: Understanding Urban Carbon Fluxes. Second State of the Carbon Cycle Report*. Ed. by N. Cavallaro et al. DOI: 10.7930/soccr2.2018.ch4.

Toronto Atmospheric Monitoring for Emissions (TAME) project

A multifaceted campaign for establishing measurement networks in the city of Toronto tracking air quality and greenhouse gas emissions to assess whether Toronto is meeting emissions reduction targets.

- Established 5 "supersites" with ground-based remote sensing instruments (EM27 FTS) providing hubs for in situ instruments.
- Designated EM27 that acts as our Toronto network "travel standard".
- Provide urban scale information on emissions of CO_2, CH_4, and CO using column gradients.
- Provide validation data for satellite-based measurements of X_{CO2}, X_{CH4}, and X_{CO}, which put Toronto emissions in the context of cities around the world.



Fibre optic (FO) tracking fully automated at 5 sites since 2024-09

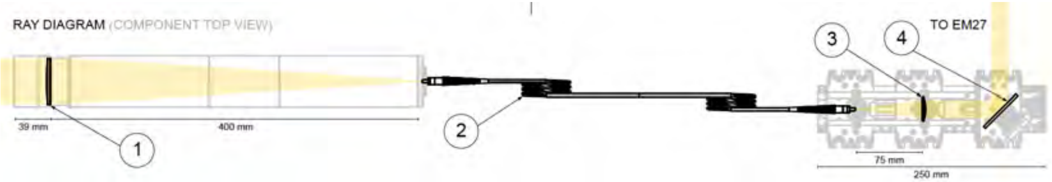
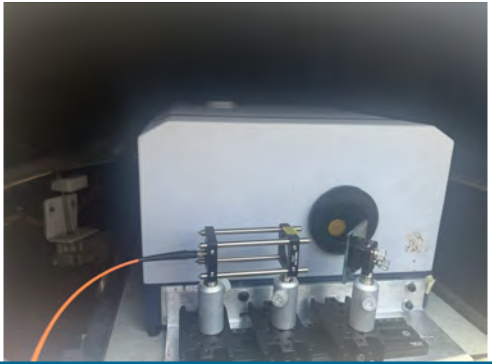


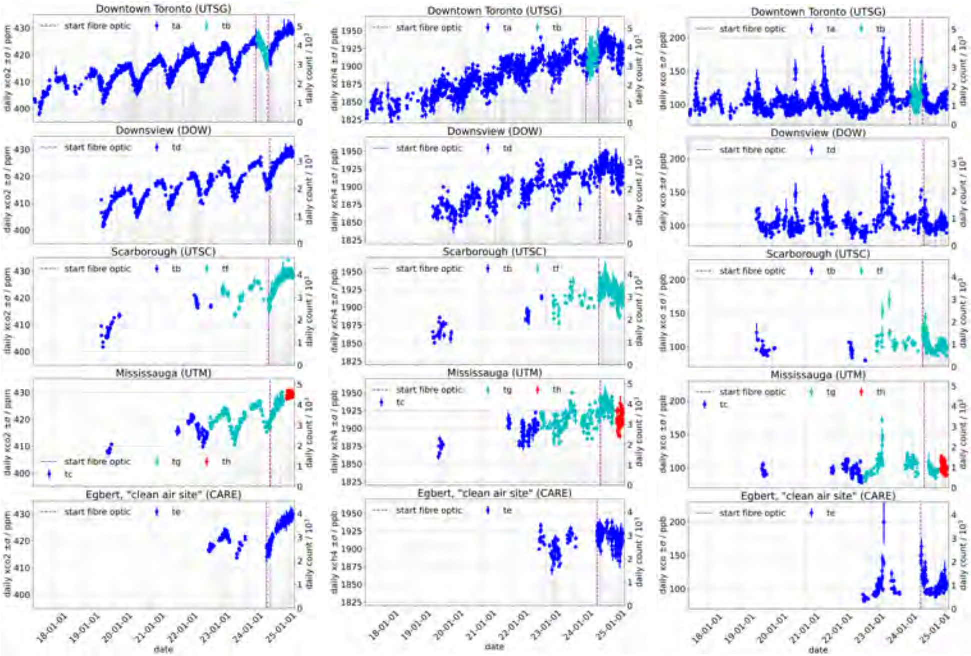
Figure: Ray diagram for FO tracking with glass lenses.

1. Telescope mounted to Eko suntracker using CaF_2 lens.
2. Optical fibre, using a 2 m long 0.22 NA, low OH silica core fibre with 550μm internal diameter. Longer fibres had too much attenuation in CO channel.
3. Second collimating lens with 75 mm focal length, also CaF_2.
4. Flat, gold-plated mirror with manual positional adjustments.

Figure: Original EM27/SUN



Building a data record with the EM27s in Toronto

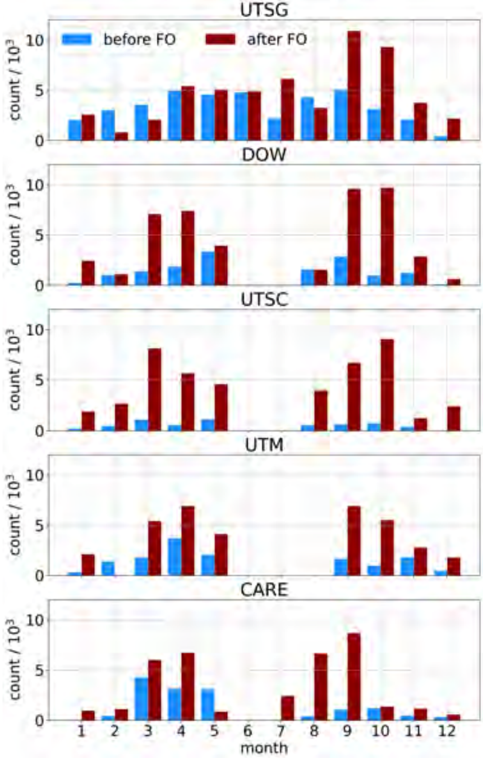


- Full records through May 2025 of X_{CO2}, X_{CH4}, and X_{CO} GGG2020 retrievals for 5 sites in Toronto.
- UTSG and DOW have the most personnel and were able to continue running through covid lock down.

More data collected with automated measurements

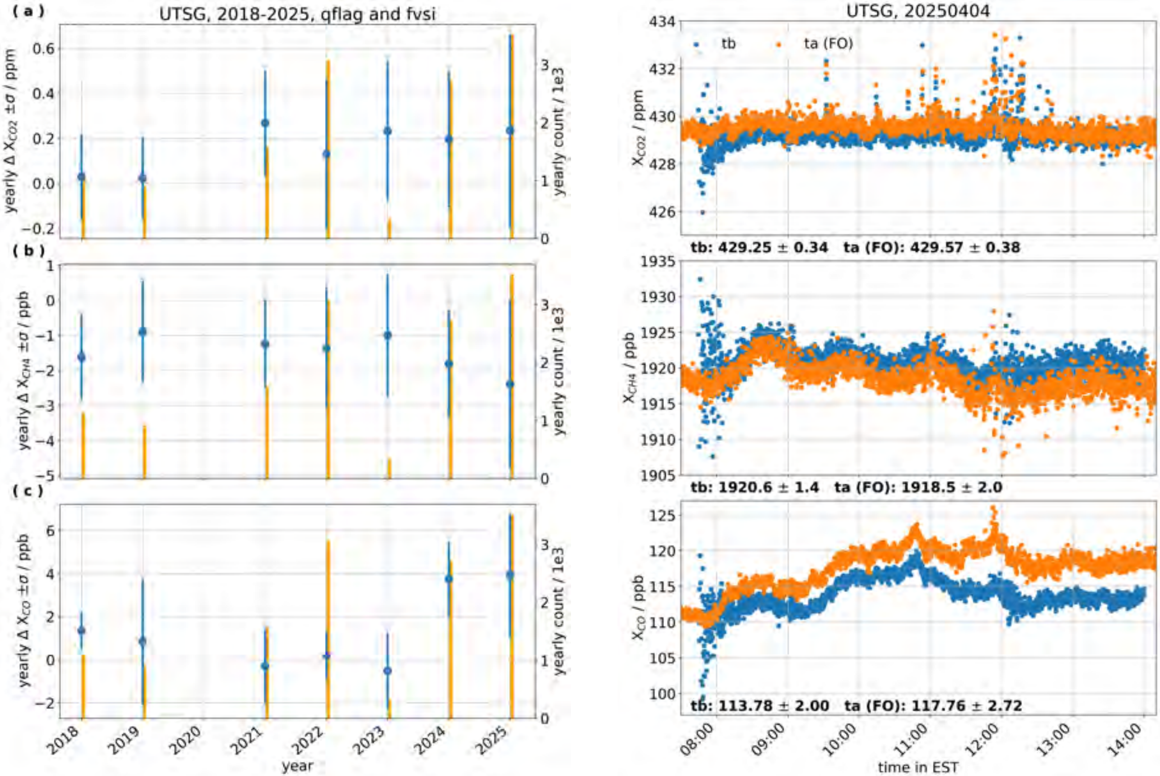
- Full automation using ASAP[a] allows data collection on days with variable condition or when no one is available. This provides large increases in data density.
- Solar tracking is continuous and consistent. It does not get lost looking for the sun is cloudy weather.
- No need to expose the instrument or tracking mirrors to the elements, means better climate control for the spectrometer.

[a] A. Geddes, J. Robinson, and D. Smale (Jan. 2018). "Python-based dynamic scheduling assistant for atmospheric measurements by Bruker instruments using OPUS". In: *Applied Optics* 4. DOI: 10.1364/ao.57.000689.

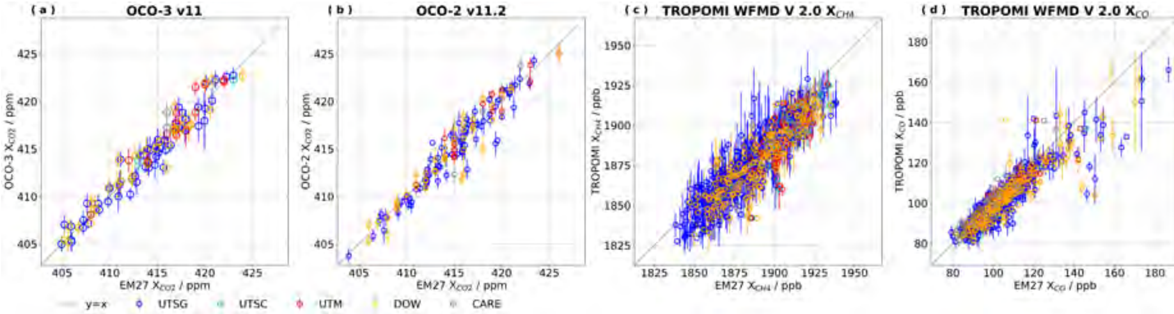


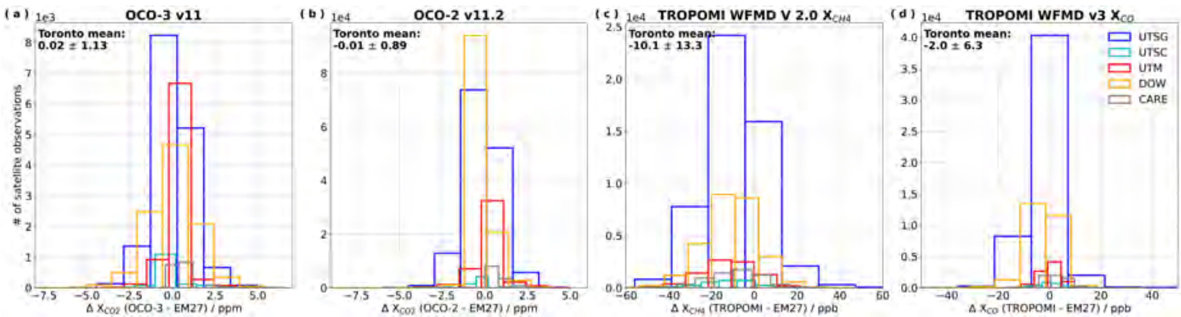
Data counts as number of one-minute averages (after quality controls) per month before and after fibre optic tracking was installed.

Comparing to the travel standard EM27 before and after FO tracking



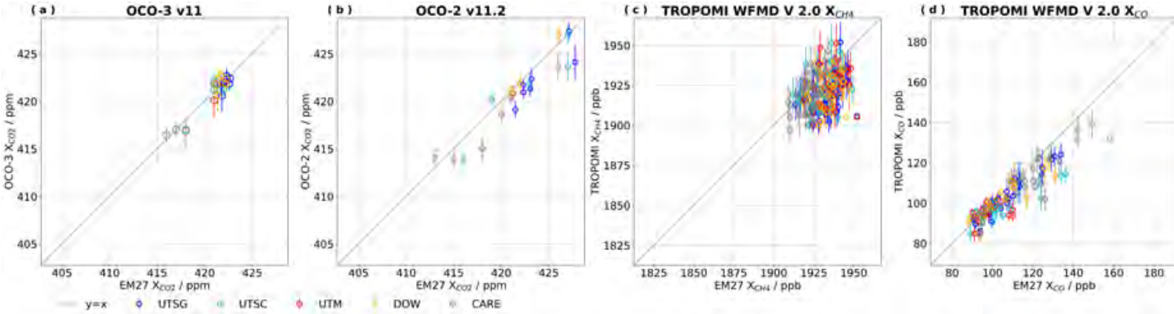
Biases in satellite-based retrievals before FO tracking

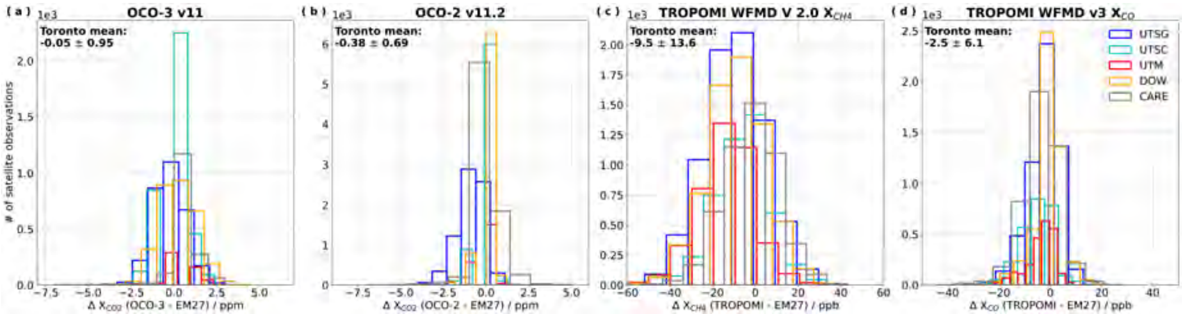




Colocation criteria: Satellite observations within a $2^\circ \times 2^\circ$ box centred on the ground site and ± 4 hours of local solar noon. Referenced to the mean of ground-based retrievals from GGG2020 ± 1 hour of local solar noon. Averaging kernel and a priori corrections applied.

Biases in satellite-based retrievals with FO tracking **(PRELIMINARY)**





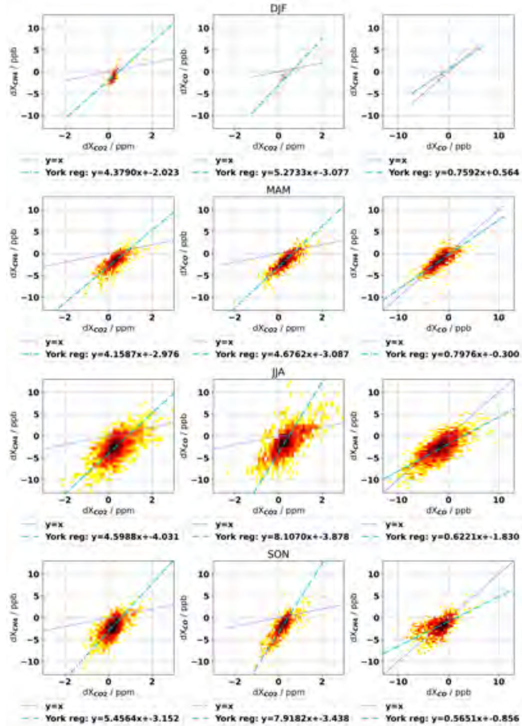
Colocation criteria: Satellite observations within a $2^\circ \times 2^\circ$ box centred on the ground site and within ± 4 hours of local solar noon. Referenced to the mean of ground-based retrievals from GGG2020 within ± 1 hour of local solar noon. Averaging kernel and a priori corrections are applied.

Starting an enhancement ratio analysis for Toronto

- Gradient enhancements ratios are calculated by using Eq. 1 and calculating the ratio of dX_{CH4}:dX_{CO2}, dX_{CO}:dX_{CO2}, or dX_{CH4}:dX_{CO} as the slope of the linear regression.

$$dXgas[site] = \frac{Xgas[site] - Xgas[reference]}{ak_{gas}^{surface}} \tag{1}$$

- We can multiply the enhancement ratio by inventory estimates of CO_2 or CO emissions, respectively, to obtain a range of CH_4 and CO emission estimates for a suite of models.



Conclusions

- Developing a long record of EM27 measurements around the city of Toronto would be a valuable asset in quantifying urban scale emissions and how they are changing over time.
- The deployment of fibre optic solar tracking for the EM27 sites around Toronto has significantly increased the quantity of observations and provided continuous measurements at sites that previously had very sparse data due to staffing shortages.
- Biases between EM27 instruments remain pretty constant for X_{CO2} and X_{CH4} before and after the implementation of fibre optic tracking, but for X_{CO} retrievals there is more variability. We are continuing to assess the data quality with this new tracking system.
- For 2019-2023, mean biases in OCO-2 and OCO-3 were < 0.1ppm $\pm \sim 1$ ppm. TROPOMI wfmd v3 has a mean bias of $-5.3\pm$ 13.3 ppb and $-1.5\pm$ 7.5 ppb for X_{CH4} and X_{CO}, respectively. Very preliminary results with FO tracking show consistent bias relative to satellite-based retrievals.
- Comparisons to satellite-based observations over Toronto will allow us to ensure our emissions estimates can be compared to other urban areas worldwide, and the increase in data collection allows us to ensure we have full coverage during more overpasses.