Identifying needs for urban greenhouse gas monitoring in Seoul using ground-based EM27/SUN measurements

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EGU23-14275
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EGU General Assembly, 23-28 April 2023, Vienna, Austria

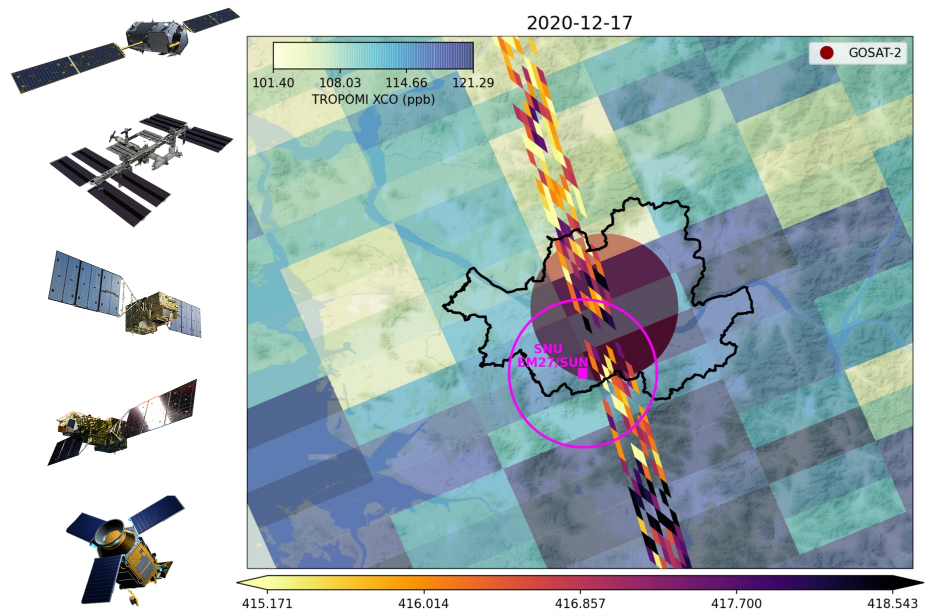
!. Background & Objectives

- To better manage atmospheric greenhouse gases, it is necessary to monitor and quantify emissions at all spatial scales, from global to national and urban levels.
- Although satellites show high precision in terms of global scale measurements, margins of error and biases still exist in observations of cities and point-source areas; therefore, validation of satellite measurements over urban areas are necessary.
- The Total Carbon Column Observing Network (TCCON) has been of great importance for monitoring atmospheric concentrations of greenhouse gases as well as validation for satellite observations. However, they are usually located in clean background sites and, due to its size and high maintenance cost, is difficult to operate in various urban sites and other emission areas.
- The COllaborative Carbon Column Observing Network (COCCON) consists of EM27/SUNs which are portable, low resolution FTIR spectrometers developed by Karlsruhe Institute of Technology (KIT) and BrukerOptics™. Using the advantage of the portability of EM27/SUNs, many of the instruments have been used to measure greenhouse gases in cities and hotspot regions.
- As part of the COCCON network, Seoul National University has been operating two EM27/SUNs, which is the first to be done in South Korea, for regular monitoring of greenhouse gases in Seoul.
- **This study provides the first comprehensive analysis of column-averaged dry air mole fractions of CO_2, CH_4, and CO (hereafter, XCO_2, XCH_4, XCO) in the atmosphere of Seoul, South Korea, using two EM27/SUNs.**
- **In addition, we compare our measurements with those of several satellite missions, including the OCO-2, OCO-3, GOSAT, GOSAT-2, and S-5PTROPOMI to assess the reliability and validity of satellite measurements over the urban area of Seoul.**

II. Data and Methods

- Two EM27/SUNs are operated at the Seoul National University (SNU) site (37.4641°N, 126.9537°E, 98 m a.s.l). We used 169 days of measurements of XCO_2, XCH_4, XCO performed from May 2020 to September 2022 observed during 12:00 KST ~ 17:00 KST.

- To compare the reliability and validity of the satellite measurements of the urban area of Seoul, we used five different satellites to make comparisons with the two EM27/SUNs located at SNU.
- A sensitivity test was made to determine the threshold of satellite measurement collocations to use for comparison with the EM27/SUNs. Satellite measurements that were made within a 0.1-degree buffer around the EM27/SUN measurement location were considered for analysis, and same day EM27/SUN spectral observations made during ±30 minutes of the satellite overpass were taken for comparison with the satellite data. For GOSAT, we gave a larger buffer of 0.5 degrees in order to obtain more satellite samples. The same collocation of ±30 minutes of the EM27/SUN measurements were used to match the observations made during the GOSAT satellite overpass.



Satellite	Data Used	Spatial Resolution	Revisit Time
OCO-2	OCO2_L2_Lite_FP 11r XCO_2	1.29 km x 2.25 km	16 days
OCO-3	OCO3_L2_Lite_FP 10.4r XCO_2	1.6 km x 2.2 km	Varies
GOSAT (FTS)	SWIR L2 bias corrected XCO_2 and XCH_4	10.5 km²	3 days
GOSAT-2 (FTS-2)	SWFP version 0200 L2 XCO_2, XCH_4, and XCO	x8~10.5 km²	6 days
S-5P TROPOMI	S-5P TROPOMI bias corrected XCH4 and the total column CO data calculated into XCO	5.5 km x 7 km	Daily

III. Results

SEOUL EM27/SUN MEASUREMENTS

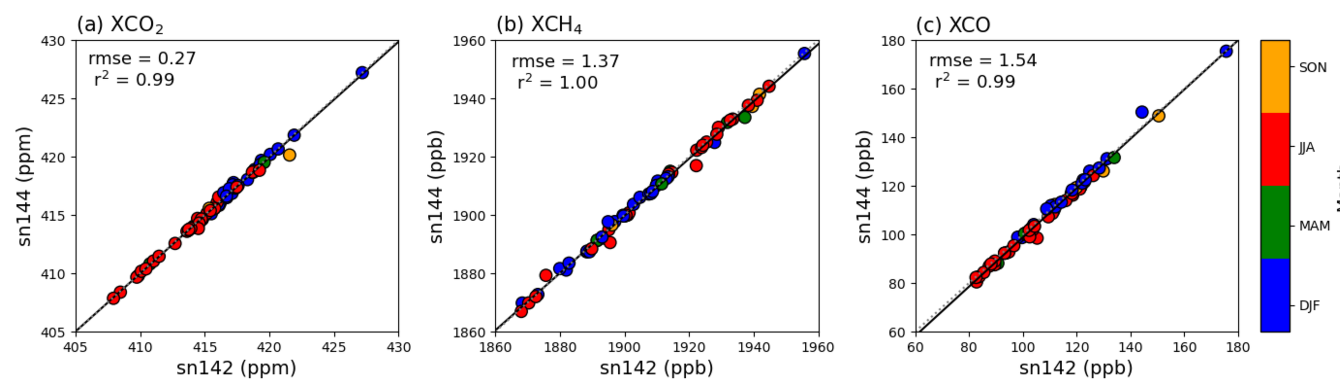


Fig.1. Comparison scatter plots of XCO_2, XCH_4, and XCO from side-by-side measurements of the two EM27/SUNs (EM27sn142 and EM27sn144). The two spectrometers show good agreement for all three measurements of XCO_2, XCH_4, and XCO ($r^2 = 0.99$, $r^2 = 1.00$, and $r^2 = 0.99$, respectively).

Fig. 2. Time series of EM27/SUN observations of (a) XCO_2, (b) XCH_4, and (c) XCO measured at Seoul National University, Seoul, South Korea.

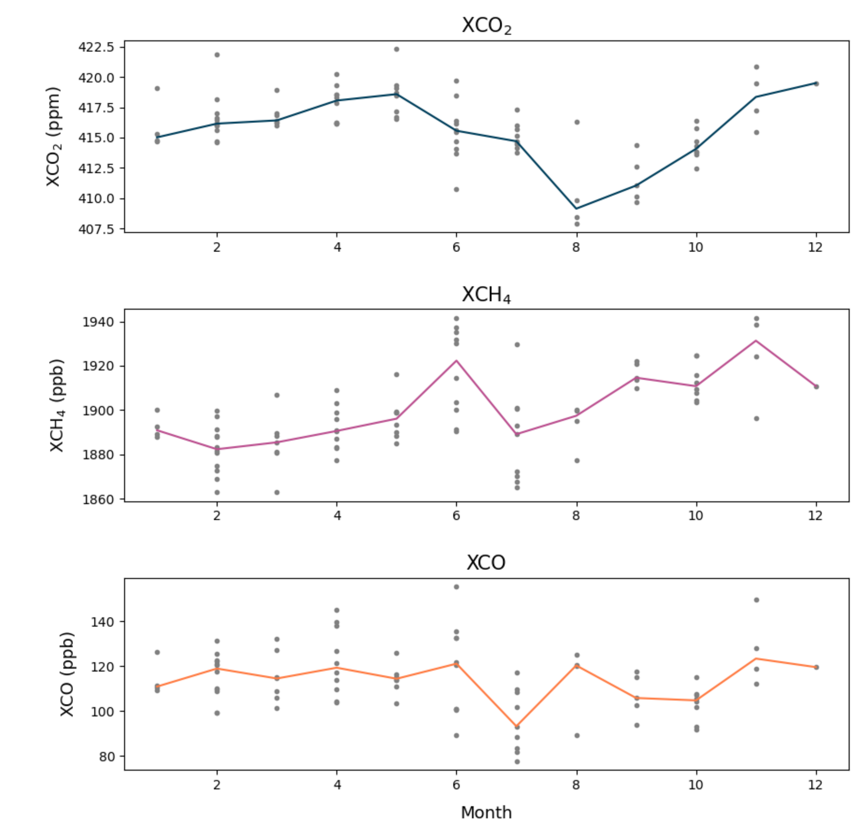


Fig. 3. Monthly median values and standard deviations of (a) XCO_2, (b) XCH_4, and (c) XCO measurements taken at the SNU site.

- Seoul EM27/SUN XCO_2 capture a clear seasonal cycle with high seasonal mean and standard deviation in the spring (418.89 ± 2.02 ppm) and low seasonal mean and standard deviation in the summer (414.73 ± 2.93 ppm) months.
- The observations of XCH_4 show the highest seasonal mean and standard deviation in autumn (1913.84 ± 16.20 ppb) and the lowest seasonal mean and standard in spring (1895.65 ± 13.71 ppb). Seoul XCH_4 measurements show similar patterns with XCH_4 measurements at Xianghe and Thessaloniki, which also show values being lower until spring, rising during the summer, and reaching a maximum in autumn.
- The daily pattern of XCO is variable and does not show a clear seasonal pattern, but shows the highest values in spring (116.73 ± 12.12 ppb) and lowest in summer (107.73 ± 18.84 ppb). This is similar to the FTIR measurements located in Karlsruhe, Pasadena, and Paris.
- Despite different seasonal patterns, all three measurements of XCO_2, XCH_4, and XCO in Seoul show agreeing patterns of peaks on high concentration days.

COMPARISONS OF SEOUL EM27/SUN AND SATELLITE OBSERVATIONS

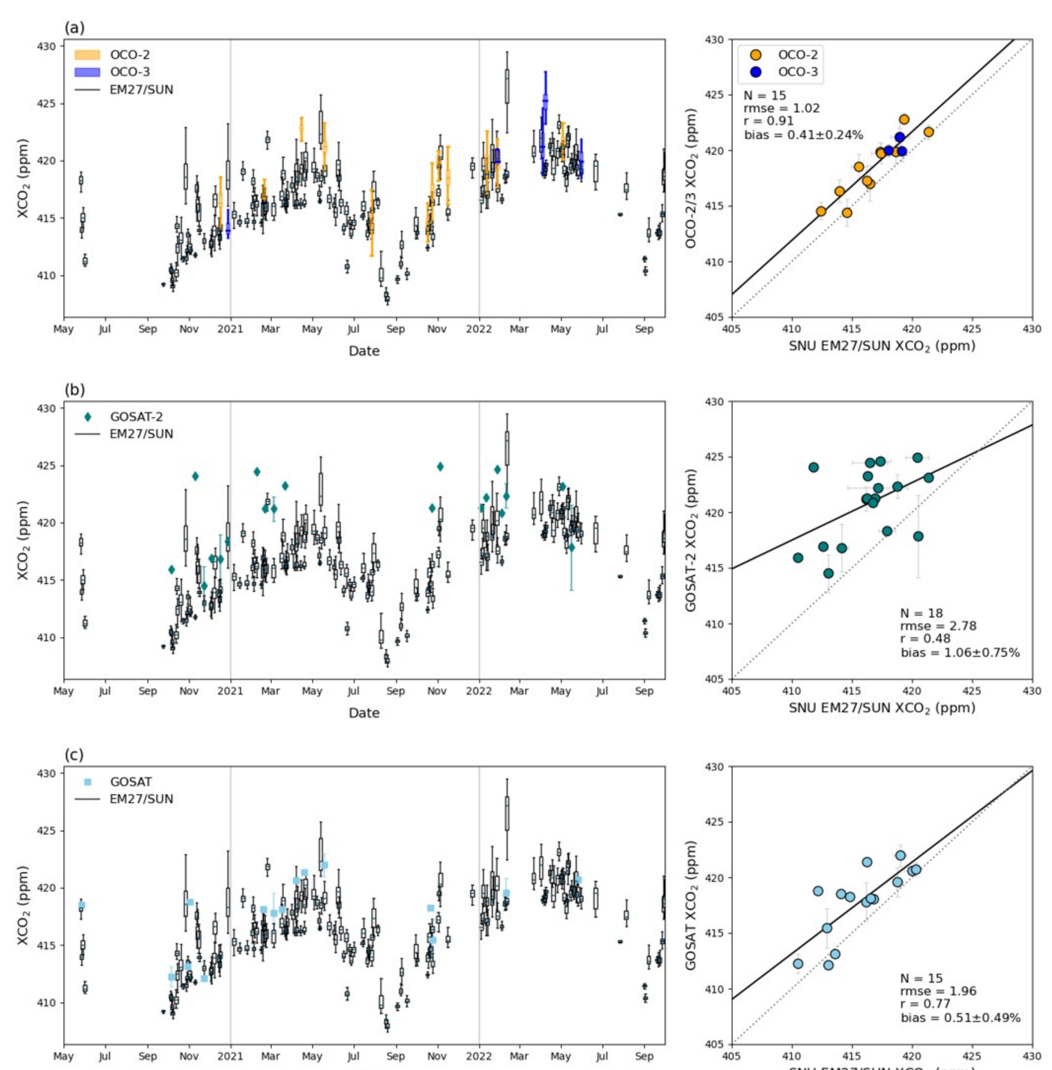


Fig. 4. Satellite comparisons of (a) OCO-2, OCO-3, (b) GOSAT-2, and (c) GOSAT XCO_2 with EM27/SUN XCO_2. Satellite soundings of OCO-2, OCO-3, GOSAT-2 within 0.1-degree buffer around measurement site were used for comparison. For GOSAT, satellite soundings within a 0.5-degree buffer around the measurement were used. EM27/SUN measurements ± 30 minutes of satellite overpass were used for comparison.

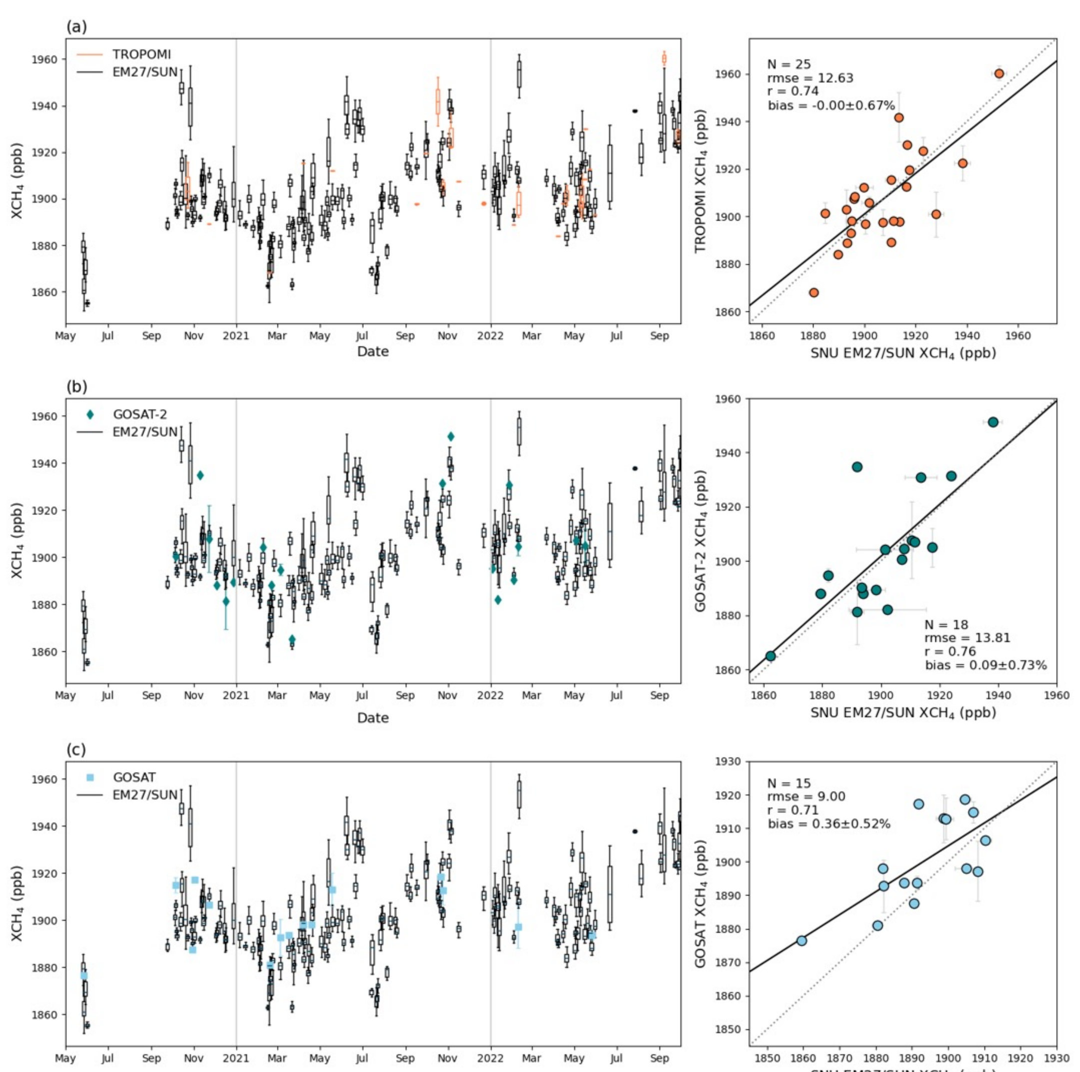


Fig. 5. Satellite comparisons of (a) TROPOMI, (b) GOSAT-2, and (c) GOSAT XCH_4 with EM27/SUN XCH_4.

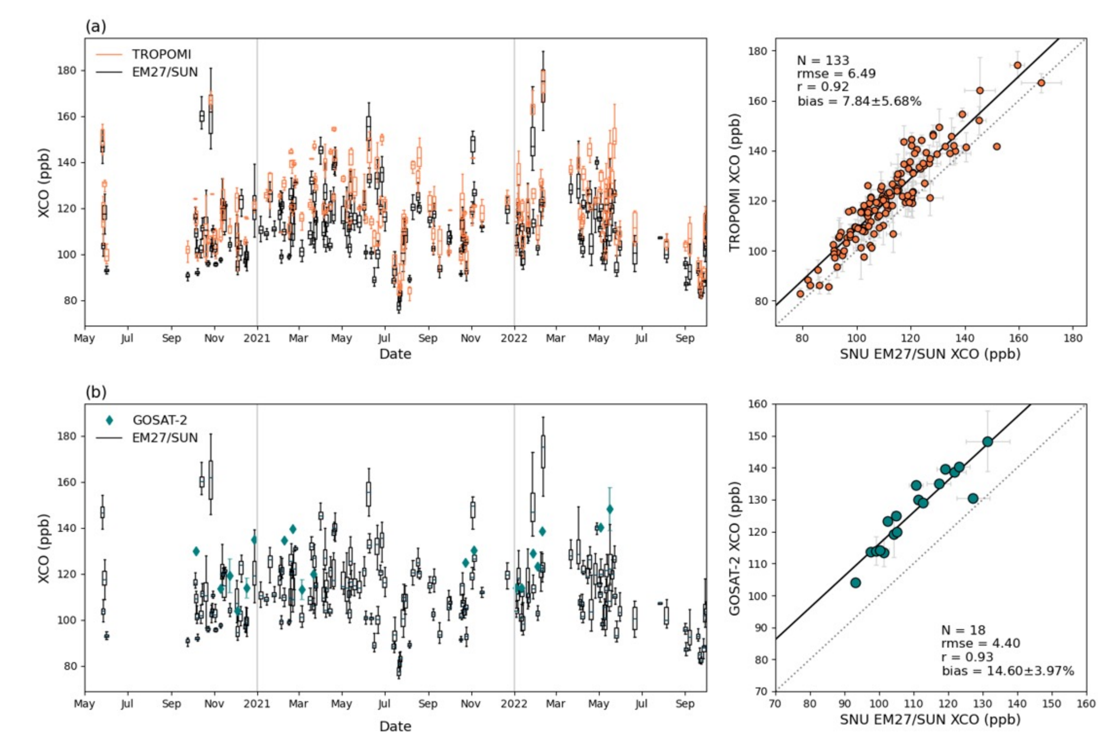


Fig. 6. Satellite comparisons of (a) TROPOMI XCO and (b) GOSAT-2 XCO with EM27/SUN XCO.

IV. Discussion & Conclusion

- We find that the two EM27/SUNs, the first to be operated in South Korea at SNU to measure long-term variations of XCO_2, XCH_4, and XCO, show good agreement and clear seasonal patterns.
- Seoul has the advantage of multiple greenhouse gas satellites targeting the city and making observations, which allows validation against our EM27/SUN measurements as well as intercomparisons with the satellite validation results.
- EM27/SUN comparisons with the OCO-2, OCO-3, GOSAT, GOSAT-2 and TROPOMI generally show good agreement in daily and seasonal patterns, with the satellites mostly having a higher bias compared to the EM27/SUNs, but well within the bias requirements of the respective satellites.
- However, GOSAT-2 XCO_2 and GOSAT XCH_4 show the lowest agreement with the Seoul EM27/SUN observations.
- More satellites with high temporal and spatial resolutions targeting local emissions or local satellite retrieval algorithms that can be applied when evaluating urban emission sources are needed for improved measurements of urban areas.
- In the case of Seoul, geostationary satellites measuring greenhouse gases will be of great advancement for urban area and hotspot monitoring.
- A combination of multiple, long-term ground-based EM27/SUN measurements with high precision satellites accommodating high temporal and spatial coverage for urban areas will be of great synergy for greenhouse gas emission monitoring as well as reaching emission reduction targets.

ACKNOWLEDGEMENT

This work was supported by Korea Environment Industry &Technology Institute (KEITI) through "Climate Change R&D Project for New Climate Regime", funded by Korea Ministry of Environment (MOE) (2022003560006)