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Supplement of

Measurement report: Insights into the high temporal variability of atmospheric carbon dioxide (CO_2) at a suburban station in the Indo-Gangetic Plain

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1 This Supporting Information file contains 1 section, 6 figures and 3 tables in 11 pages.

S1. Calibration details

The Picarro G2301 analyser was calibrated using four NOAA-certified primary standard cylinders containing known concentrations of CO2 and CH4 (Table S3). Each cylinder was sampled for 15 minutes in an ascending concentration sequence, repeated twice (Figure S6), resulting in a total measurement time of 30 minutes per cylinder over a 2-hour session. An automated multiport valve controller handled the switching between cylinders to ensure consistency and reduce manual error, while also testing the instrument's stability during calibration. Minute averages and standard deviations were calculated after excluding the initial 3–4 minutes of each run to allow for stabilisation (Laurent, 2016). Only minute averages with standard deviations below 0.04 ppm for CO_2 and 0.0004 ppm for CH_4 were used. These were averaged first per sequence and then across sequences to determine final mean values and standard deviations for each cylinder.

A weighted least squares regression was used to generate a linear calibration curve of the form:

$$Y = a_0 + (a_1 \times x) \quad \text{(S1)}$$

where x is the certified concentration (NOAA value) and y is the analyser's reading. For correcting measured values, the inverse was applied:

$$X = \frac{(y - a_0)}{a_1} \quad \text{(S2)}$$

The four standard cylinders were chosen to cover the expected concentration range at the site, and the primary calibration was performed annually.

S2. Details of other monitoring stations

The comparison sites include five Indian monitoring stations and six international stations. The five Indian sites that reported CO2 mole fraction were Shadnagar (SDN; 17.09° N, 78.2° E), Gadanki (GDN; 13.50° N, 79.20° E), Mohali (MHL; 30.67° N, 76.73° E), Sinhagad (SNG; 18.21° N, 73.45° E) and Ahmedabad (AHM; 23.03° N, 72.55° E). Apart from Indian sites, six sites in the same latitudinal band (using ObsPACK) were compared. These sites were Mauna Lou (MLO; 19.54° N, 155.58° W), South Carolina (SCT; 33.40° N, 81.83° W), Shenandoah National Park (SNP; 38.61° N, 78.35° W), Walnut Grove, (WGC; 38.26° N, 121.49° W), Moody (WKT; 31.31° N, 97.33° W) and Boulder (BAO; 40.05° N, 105.00° W). Figure 7b compares the seasonal amplitude of the sites in the chosen latitudinal band. The inset in Figure 7b shows the location of all the measurement sites. For all non-Indian sites except BAO, the five-year average (2018-2022) has been chosen for the seasonality. For BAO, 2011-2016 has been used for this study (due to a lack of coinciding data).

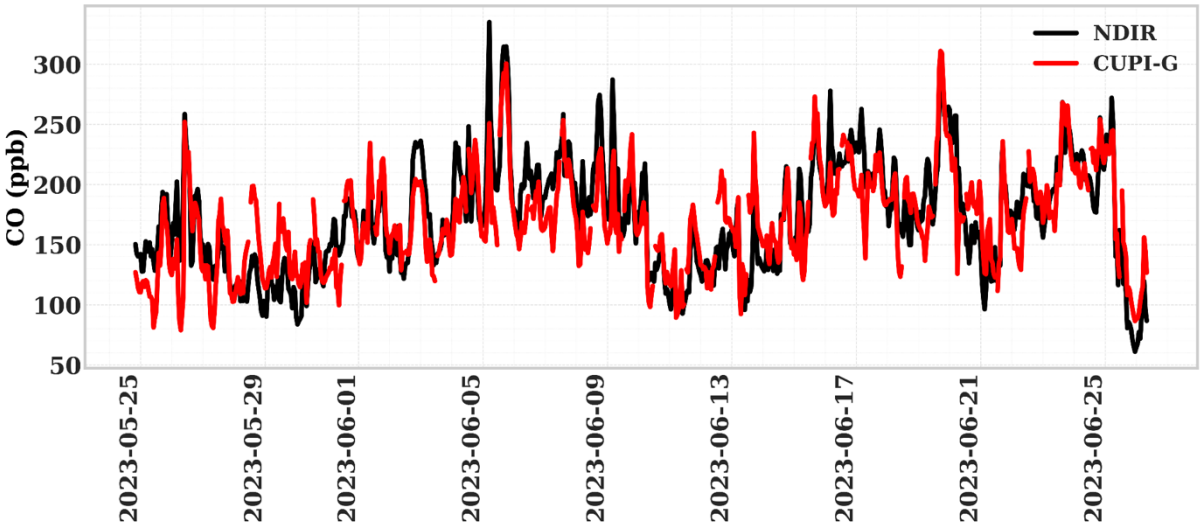

Figure S1: Comparison of CO from CUPI-G (red) with Thermo Scientific Model 48i/48j CO Analyser (NDIR) at Nagasaki University during the calibration period (May-June 2023)

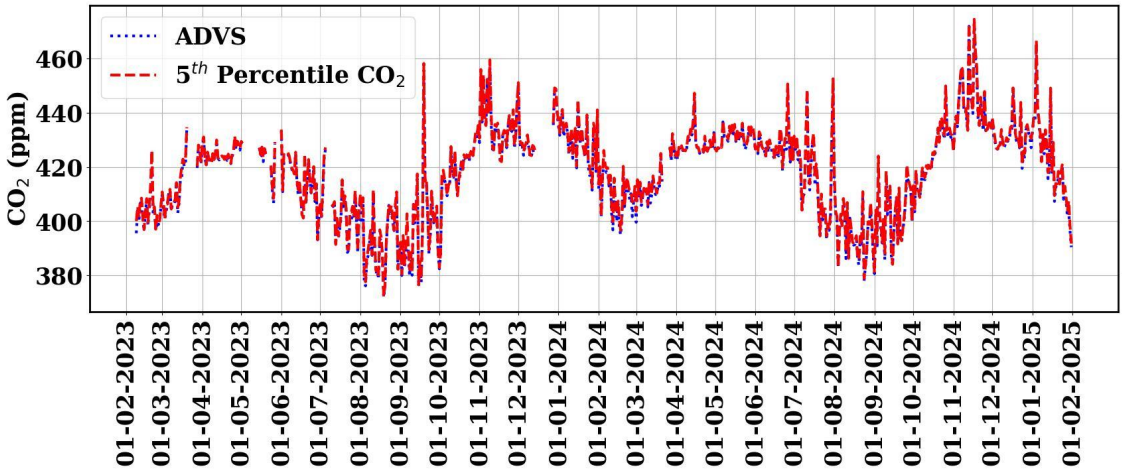

Figure S2: Comparison of background concentrations of atmospheric CO_2 estimated using the Adaptive Diurnal Variation Selection (ADVS) method and the fifth percentile method for the study period.

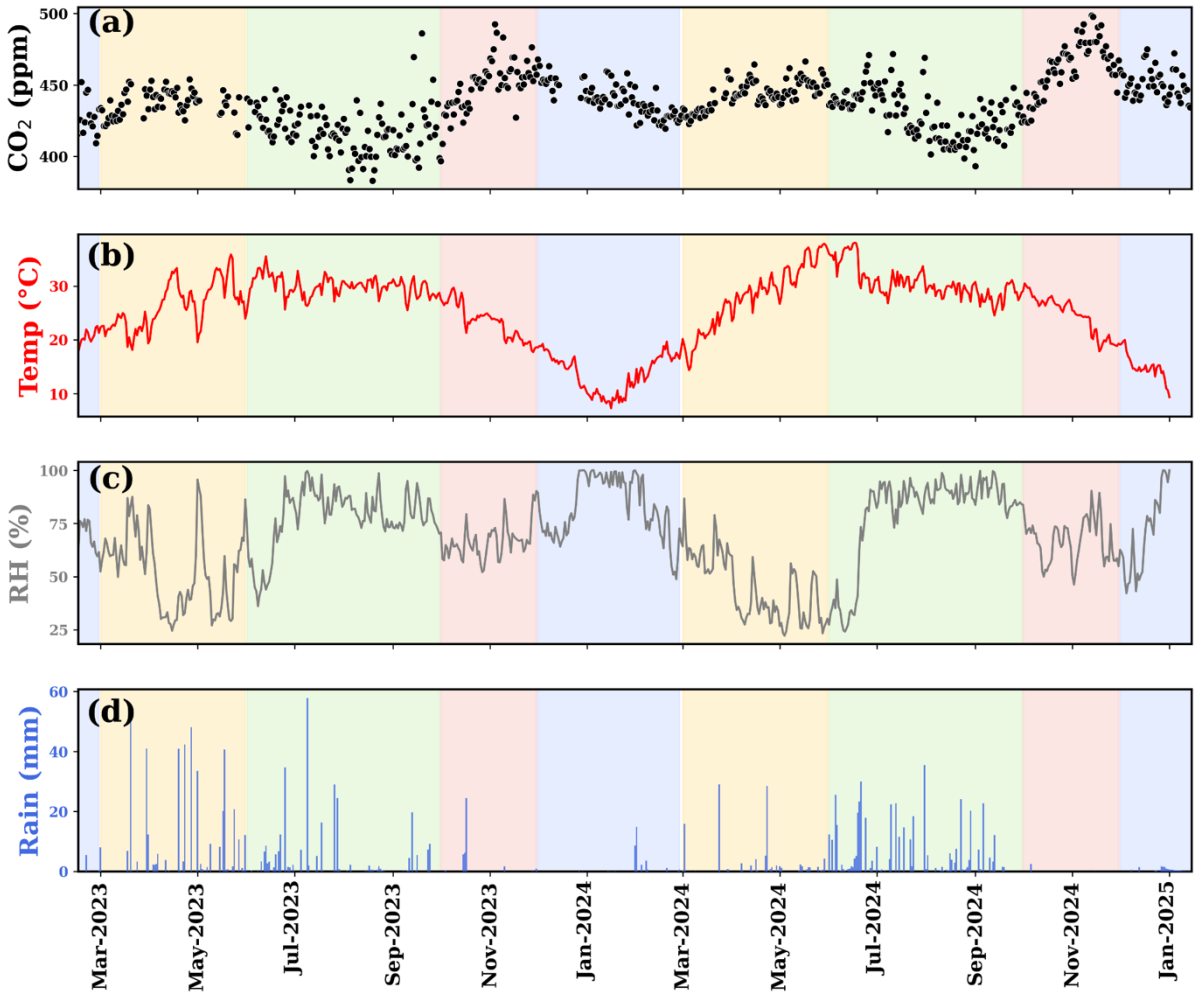

Figure S3: Daily variation in atmospheric carbon dioxide concentrations (a) and meteorological parameters (air temperature relative humidity and rain) over Sonipat (b-d) during the study period. All measurements have been made using the Automatic Weather Station (AWS) in Sonipat.

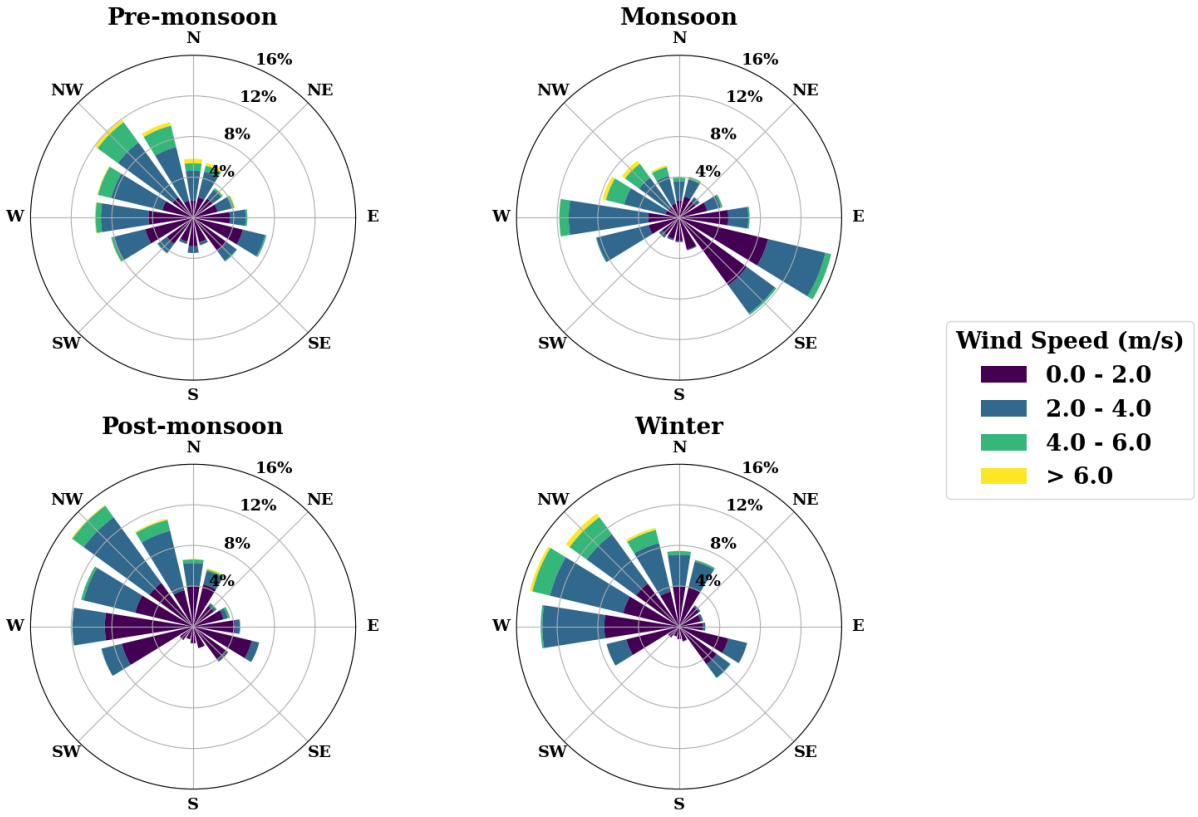

Figure S4: Seasonal variation in the wind pattern over Sonipat during the study period.

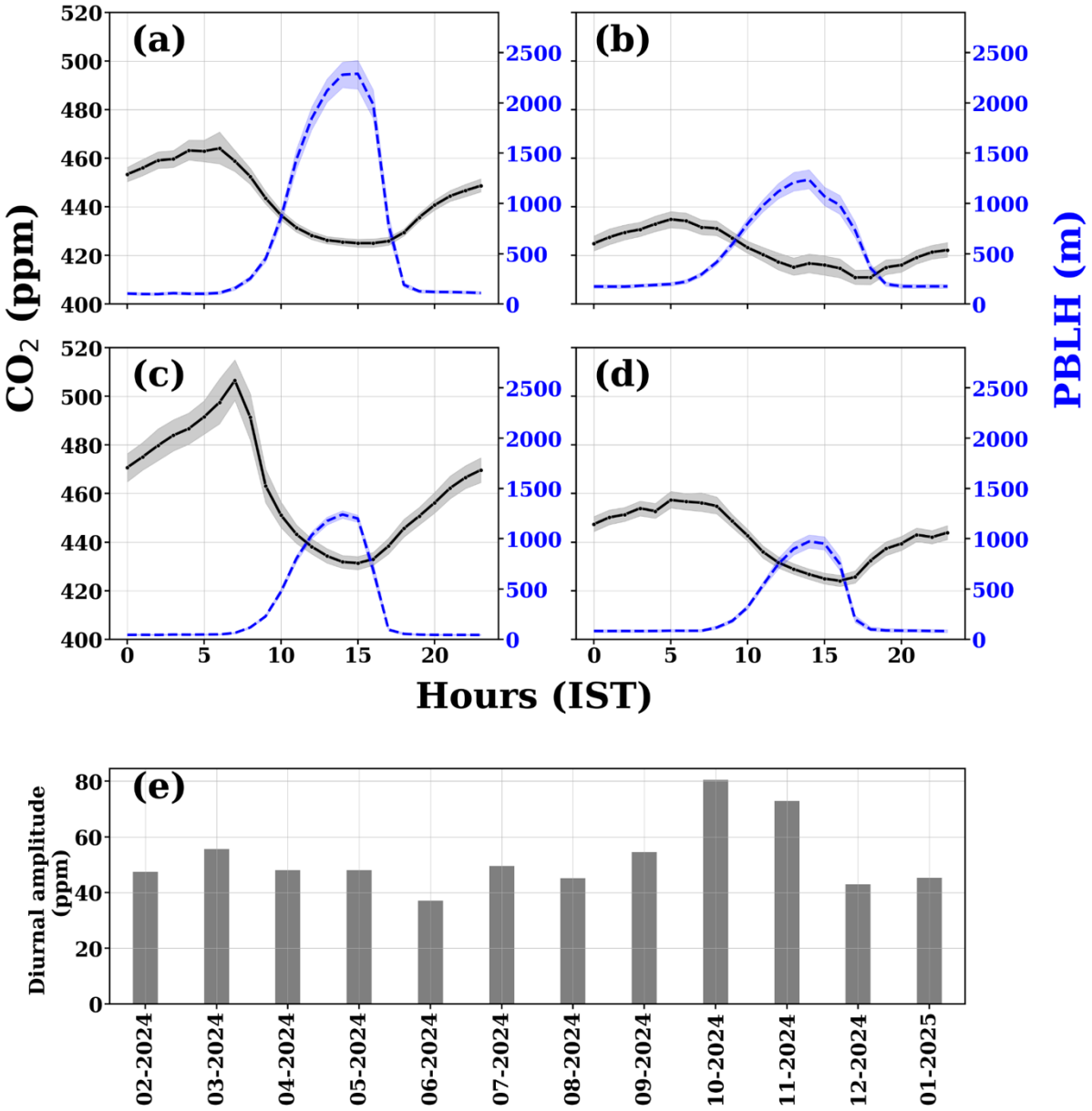

Figure S5: (a - d) Average diurnal variation of CO_2 over Sonipat during the pre-monsoon (MAM), monsoon (JJAS), post-monsoon (ON) and winter (DJF) seasons with planetary boundary layer height (blue), (e) monthly variation of the average diurnal amplitude of CO_2 from February 2024 to January 2025.

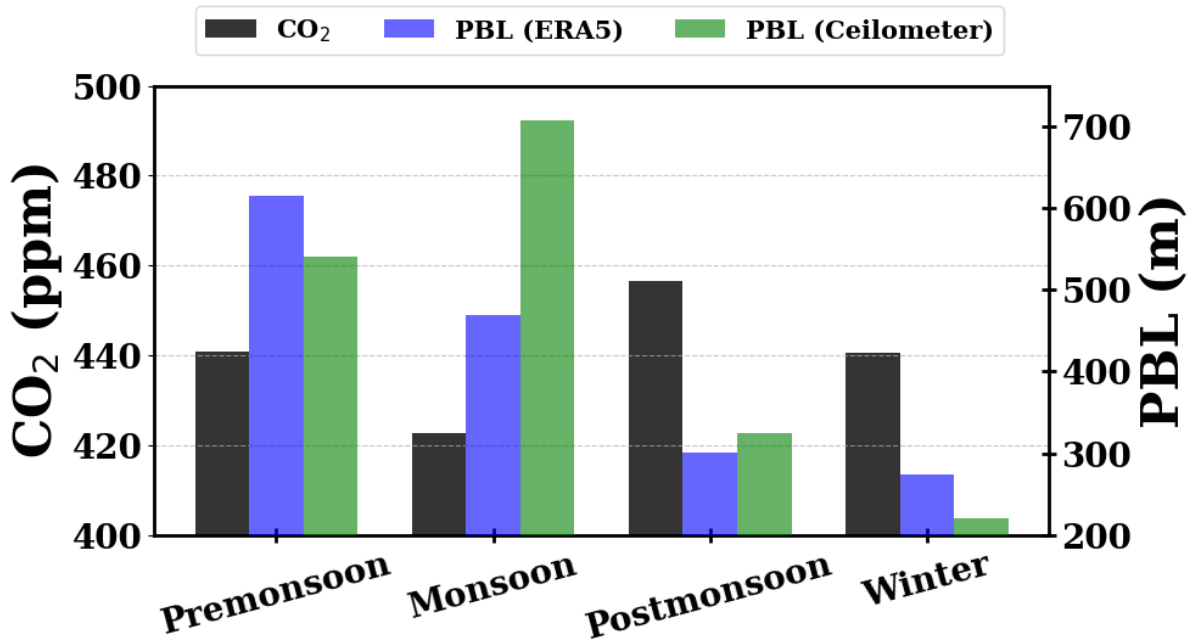

Figure S6: Comparison of seasonal means of atmospheric CO_2 concentrations with PBLH over Sonipat.

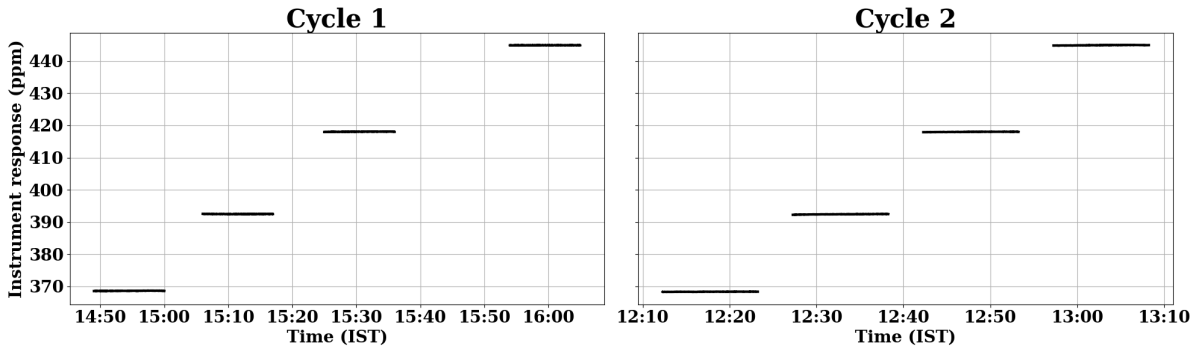

Figure S7: Calibration procedure using four NOAA-certified standard gases for CO_2 and CH_4.

Table S1: Annual, seasonal mean, and seasonal variation of the average diurnal amplitude of CO_2 over Sonipat during the study period compared with other study sites over India. Seasons have been defined as pre-monsoon (MAM), monsoon (JJAS), post-monsoon (ON), and winter (DJF).

Location	Site	Study Period	Reference	Annual Mean (ppm)	Pre-monsoon		Monsoon		Post-monsoon		Winter	
					Mean (ppm)	Diurnal Amplitude (ppm)	Mean (ppm)	Diurnal Amplitude (ppm)	Mean (ppm)	Diurnal Amplitude (ppm)	Mean (ppm)	Diurnal Amplitude (ppm)
Sonipat, Haryana	Semi-urban	Feb 2023 – Jan 2025	This study	440.8	440.8	49.9	422.6	46.3	456.4	69.6	440.5	44.5
Mohali, Punjab*	Semi-urban	Jan 2017 – Dec 2017	Thilakan et al., 2023	428.8	~ 409.0		~ 400.2		~ 417.5		406.7	
Ahmedabad, Gujarat*	Urban	Nov 2013 – May 2015	Chandra et al., 2016	413.0	~ 413.3	~ 10.0	~ 401.7	~ 10.0	~ 422.5	~ 40.0	~ 420.0	~ 30.0
Sinhagad, Maharashtra	Semi-urban	Jul 2014 - Nov 2015	Metya et al., 2021	406.1	416.9	2.8	400.2	10.0	401.8	4.1	409.9	1.9
Shadnagar, Telangana**	Semi-urban	Jan 2014 – Dec 2014	Sreenivas et al., 2016	394.0	~ 394.5	~ 25.0	~ 386.3	~ 15.0	~386.5	~ 17.0	~ 383.5	~15.0
Gadanki, Andhra Pradesh*	Rural	Apr 2016 – Apr 2019	Jain et al., 2021	420.0	419.8	~ 20.0	414.2	~ 23.0	423.7	~ 55.0	421.8	~ 35.0

* Monsoon has been defined as JJA, and post-monsoon has been defined as SON.

** Post-monsoon has been defined as OND.

Table S2: Seasonal amplitude of CO_2, peak, and draw-down months over Sonipat during the study period compared with other study sites over India. Seasons have been defined as pre-monsoon (MAM), monsoon (JJAS), post-monsoon (ON), and winter (DJF).

Location	Site	Study Period	Reference	CO_2 Peak (month) (ppm)	CO_2 Draw-down (month) (ppm)	Seasonal Amplitude (ppm)
Sonipat, Haryana	Semi-urban	Feb 2023 – Jan 2025	This study	470 (November)	410 (August)	60
Mohali, Punjab*	Semi-urban	Jan 2017 – Dec 2017	Thilakan et al., 2023	420 (November)	390 (August)	30
Ahmedabad, Gujarat*	Urban	Nov 2013 – May 2015	Chandra et al., 2016	425 (November)	390 (July)	35
Sinhagad, Maharashtra	Semi-urban	Jul 2014 - Nov 2015	Metya et al., 2021	428 (May)	398 (October)	30
Shadnagar, Telangana**	Semi-urban	Jan 2014 – Dec 2014	Sreenivas et al., 2016	405 (September)	390 (May)	15
Gadanki, Andhra Pradesh*	Rural	Apr 2016 – Apr 2019	Jain et al., 2021	425 (November)	405 (Augist)	20

Table S3: Details of the calibration using the NOAA cylinders.

		Reference value		Measured value	
	Cylinder serial no	**CO_2 (ppm)**	**CH_4 (ppb)**	**CO_2 (ppm)**	**CH_4 (ppb)**
	CY1:-CB11849	370	1720	368.61 ± 0.03	1743.4 ± 0.2
Cycle 1	CY2:-CB11881	395	1837	392.47 ± 0.03	1844.2 ± 0.2
	CY3:-CB11841	420	1880	418.05 ± 0.04	1899.3 ± 0.2
	CY4:-CB11973	450	2100	444.90 ± 0.02	2104.1 ± 0.2
	CY1:-CB11849	370	1720	368.33 ± 0.03	1743.4 ± 0.2
Cycle 2	CY2:-CB11881	395	1837	392.39 ± 0.06	1844.0 ± 0.1
	CY3:-CB11841	420	1880	417.99 ± 0.05	1899.3 ± 0.1
	CY4:-CB11973	450	2100	444.91 ± 0.06	2104.1 ± 0.2