



Supplement of

Versatile soil gas concentration and isotope monitoring: optimization and integration of novel soil gas probes with online trace gas detection

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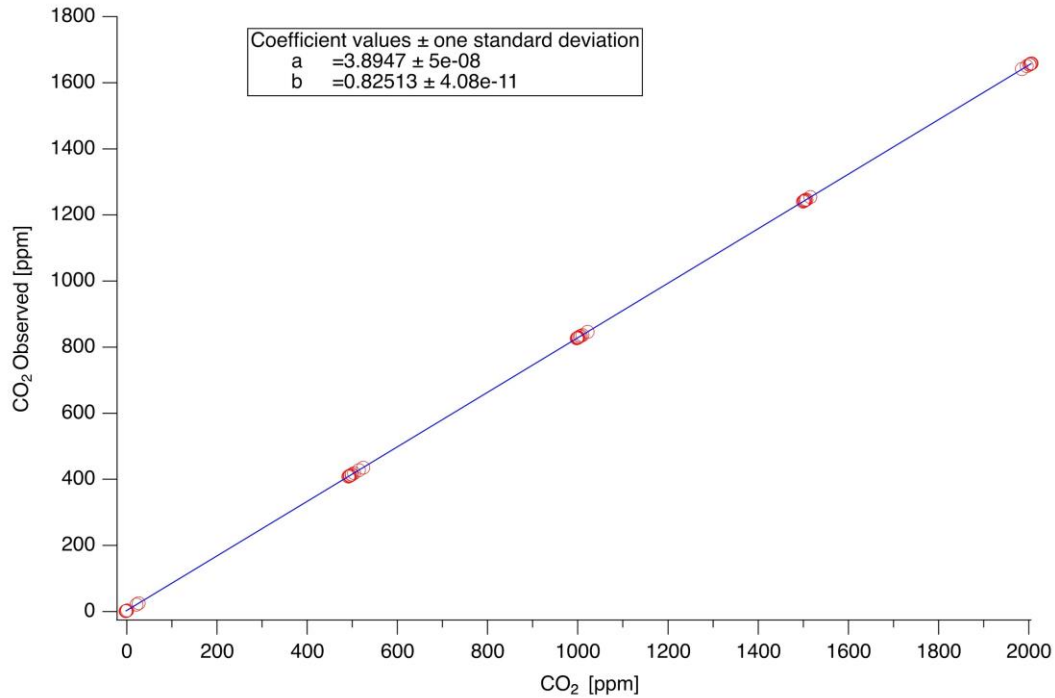


Figure S1. Calibration of absolute concentration of CO₂ in silica matrix (System 1 Dual) between observed and controlled dilution mixtures using linear regression relationship

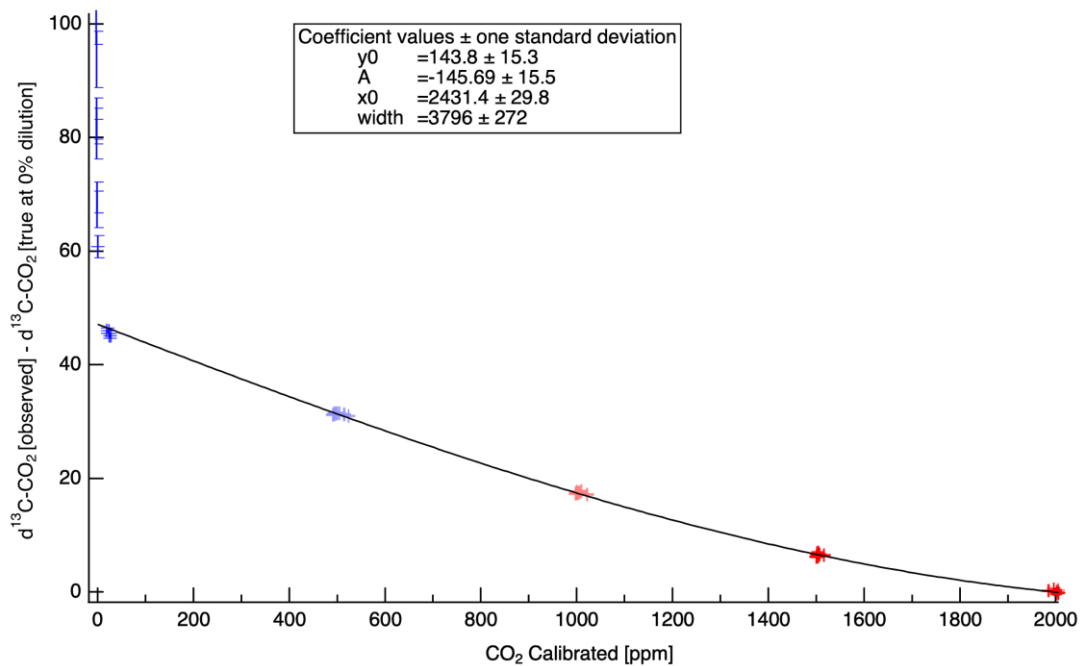


Figure S2. $\Delta^{13}\text{C-CO}_2$ calibration from the concentration dependent relationship of dual $\delta^{13}\text{C-CO}_2$ vs observed [CO₂]. The Gaussian equation was used to fit the relationship between ($\delta^{13}\text{C-CO}_2$ observed - $\delta^{13}\text{C-CO}_2$ true and CO₂ concentration. $\delta^{13}\text{C-CO}_2$ calibration offset calibration curve was used to correct observations.

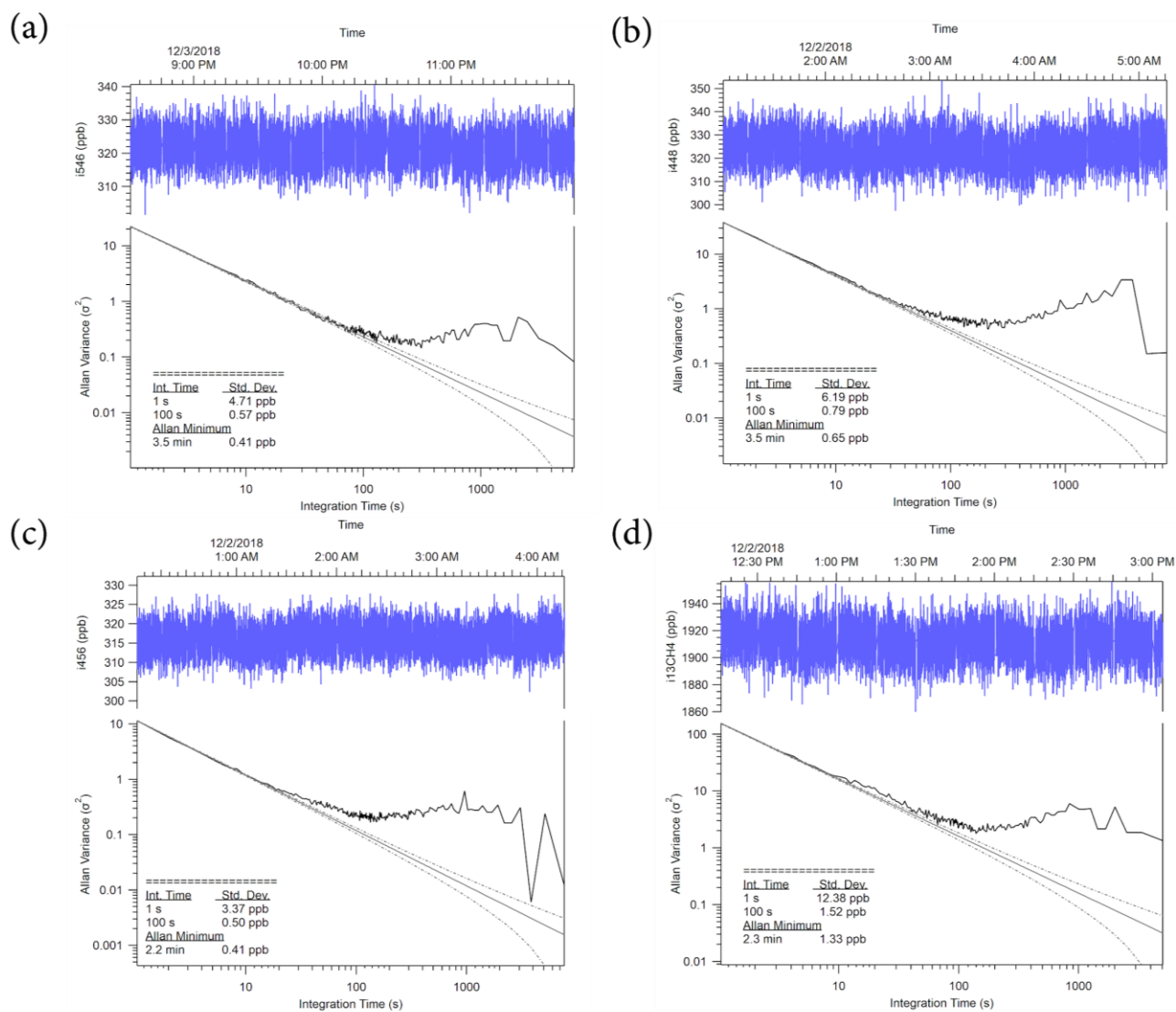


Figure S3. Allan-Werle plots of precision for individual minor isotopes N_2O 456 and 546 (top), 448 and $^{13}\text{C}-\text{CH}_4$ (bottom). Precision for $\delta 456 = 1.3 \text{ ‰}$, $\delta 456 = 1.4 \text{ ‰}$, $\delta 448 = 2.2 \text{ ‰}$, and $\delta^{13}\text{C} = 0.7 \text{ ‰}$

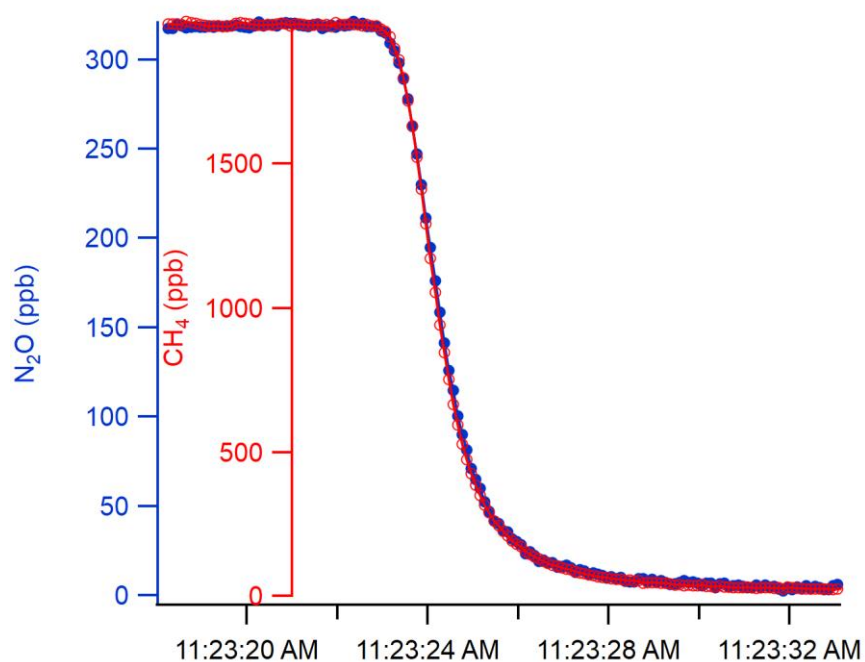


Figure S4. Improvement in the time response with the addition of the insert. Time Response of 76m standard cell with insert. P=30 Torr, flow 1 slpm.

Table S1. Soil matrix description and particle size distribution

Type of Matrix	Soil ID	Vendor	Particle size distribution (units)	Type of soil
Granusil 4095¹	Silica	Covia Corporation	8 (0%), 16 (0.28%), 20 (27.66%), 30 (52.55%), 40 (15.99%), 50 (3.22%), 70 (0.22%), 100 (0.04%), 140 (0.02%), 200 (0.28%) ^a	High purity industrial quartz, Hardness (Mohs) 7.0, Moisture content <0.1%.
Type of Soil	Soil ID	Source Site	Sampling Location	Properties
Tropical Rainforest	Soil 1	Biosphere 2 Tropical	Shaded Lowland (dieffenbachia, vine)	Sandy, silty loam (40-70% sand 36% silt and 30% clay) ^b ; and C:N 8.75; pH 7-8 ^c
Tropical Rainforest	Soil 3	Rainforest	South facing terrace (ginger, hibiscus)	

^a Mesh units ASTM; ^b (Lin et al., 1999) in (Smith et al., 2020); ^c (Van Haren et al., 2005)

Table S2. Measurement precision of the 76 m dual TILDAS for N₂O/CH₄ isotopes

	Mixing Ratio (ppb)	δ (‰)
δ546 N₂O (¹⁵ N ¹⁴ N ¹⁶ O)	0.46	1.4
δ456 N₂O (¹⁴ N ¹⁵ N ¹⁶ O)	0.42	1.3
δ448 N₂O (¹⁴ N ¹⁴ N ¹⁸ O)	0.72	2.2
¹³C-CH₄	1.3	0.7

Table S3. References used to estimate the 3D map for N₂O isotopic signatures of bulk δ¹⁵N (x-axis), δ¹⁸O (y-axis), and site preference (z-axis) (Figure 12b).

Microbial activity	Reference
Bacterial Denitrification	(Frame and Casciotti, 2010; Sutka et al., 2006; Toyoda et al., 2005; Zou et al., 2014)
Chemodenitrification	(Jones et al., 2015; Toyoda et al., 2005; Wei et al., 2017)
Bacterial nitrification	(Jung et al., 2014; Sutka et al., 2006; Yoshida, 1988)
AOA	(Hu et al., 2015)
Fungal denitrification	(Sutka et al., 2008)

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