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Correction and calibration protocol for isotope data via CRDS: a study case for N_2O and other isotope systems

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Supplementary information

S.1 Experimental Setups and Workflows

Below, we provide a detailed description of the specific setup and conditions for each experiment conducted.

S.1.1 N_2O non-linearity (Exp. 1)

The experimental setup for Exp. 1 was designed to investigate the effect of N_2O concentrations on apparent δ-values. Nitrous oxide target concentrations were set in the range of 0.350 to 1.200 ppm, depending on the CRDS investigated (See Section 3.1 for details). The target concentrations were achieved by adjusting calibration and dilution gas flows while maintaining a constant total flow of 1000 mL min^{-1} (Table S1). Each mixture was measured in triplicate across three independent experiments to ensure reproducibility. A schematic of the gas mixing and measurement system is provided in Fig. S1.

Table S1: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 1

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
N_2O (ppm)	0.35	0.425	0.5	0.575	0.65	0.725	0.8	0.99
Target flows								
Cal 1 / Cal 2	3.9	4.7	5.6	6.4	7.2	8.1	8.9	11.0
Dilution Gas	996.1	993.8	991.3	986.3	976.3	966.3	956.3	989.0
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

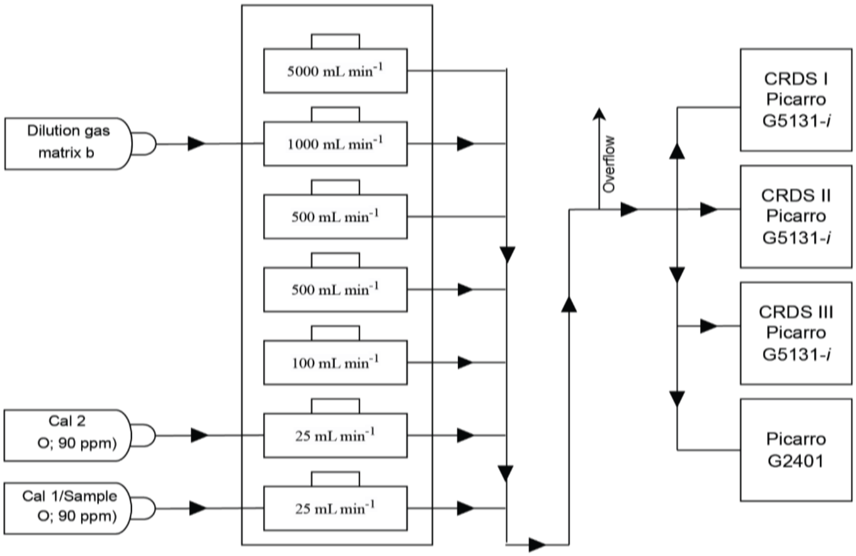

Figure S1: Schematic illustration of the experimental setup used for Exp. 1

S.1.2 CH_4 spectral interference (Exp. 2)

The experimental setup for Exp. 2 was designed to investigate the effect of CH_4 concentrations on apparent δ-values of N_2O. Nitrous oxide target concentrations were set to 0.330, 0.660, and 0.990 ppm, while CH4 were changed in the range from 0.5 to 10 ppm, and was achieved by adjusting calibration and dilution gas flows while maintaining a constant total flow of 1000 mL min^{-1} (Table S2–S4). Each mixture was measured in triplicate across three independent experiments to ensure reproducibility. A schematic of the gas mixing and measurement system is provided in Fig. S2.

Table S2: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 2

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CH_4 (ppm)	0	0.5	1	2	4	6	8	10
N_2O (ppm)	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
Target flows								
Cal 1 / Cal 2	3.67	3.67	3.67	3.67	3.67	3.67	3.67	3.67
Interferent test gas (CH_4)	0	2.5	5	10	20	30	40	50
Dilution Gas	996.3	993.8	991.3	986.3	976.3	966.3	956.3	946.3
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

Table S3: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 2

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CH_4 (ppm)	0	0.5	1	2	4	6	8	10
N_2O (ppm)	0.330	0.666	0.666	0.666	0.666	0.666	0.666	0.666
Target flows								
Cal 1 / Cal 2	3.67	7.33	7.33	7.33	7.33	7.33	7.33	7.33
Interferent test gas (CH_4)	0	2.5	5	10	20	30	40	50
Dilution Gas	992.7	990.2	987.7	982.7	972.7	962.7	952.7	942.7
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

Table S4: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 2

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CH_4 (ppm)	0	0.5	1	2	4	6	8	10
N_2O (ppm)	0.330	0.990	0.990	0.990	0.990	0.990	0.990	0.990
Target flows								
Cal 1 / Cal 2	3.67	11	11	11	11	11	11	11
Interferent test gas (CH_4)	0	2.5	5	10	20	30	40	50
Dilution Gas	992.7	986.5	984.0	979.0	969.0	959.0	949.0	939.0
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

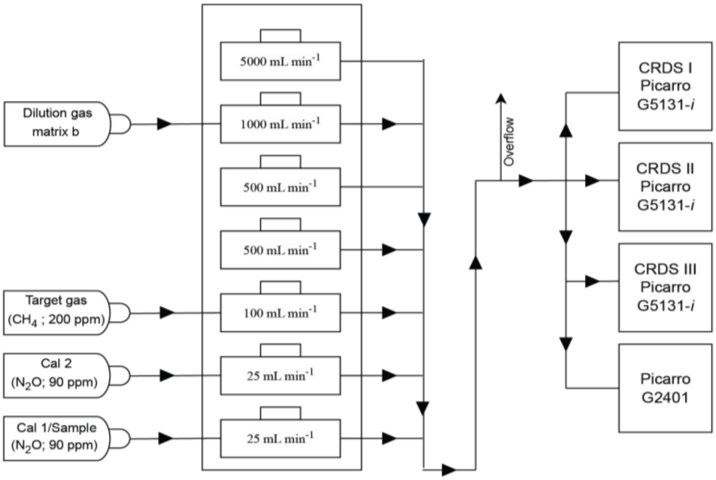

Figure S2: Schematic illustration of the experimental setup used for Exp. 2

S.1.3 CO_2 spectral interference (Exp. 3)

The experimental setup for Exp. 3 was designed to investigate the effect of CO_2 concentrations on apparent δ-values of N_2O. Nitrous oxide target concentrations were set to 0.330, 0.660, and 0.990 ppm, while CO_2 were changed in the range from 0 to 2000 ppm, and was achieved by adjusting calibration and dilution gas flows while maintaining a constant total flow of 1000 mL min^{-1} (Table S5–S7). Each mixture was measured in triplicate across three independent experiments to ensure reproducibility. A schematic of the gas mixing and measurement system is provided in Fig. S3.

Table S5: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 3

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CO_2 (ppm)	0	0	250	500	750	1000	1500	2000
N_2O (ppm)	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
Target flows								
Cal 1 / Cal 2	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Interferent test gas (CO_2)	0.0	0.0	6.3	12.5	18.8	25.0	37.5	50.0
Dilution Gas	996.3	996.3	990.1	983.8	977.6	971.3	958.8	946.3
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

Table S6: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 3

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CO_2 (ppm)	0	0	250	500	750	1000	1500	2000
N_2O (ppm)	0.330	0.660	0.660	0.660	0.660	0.660	0.660	0.660
Target flows								
Cal 1 / Cal 2	3.7	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Interferent test gas (CO_2)	0.0	0.0	6.3	12.5	18.8	25.0	37.5	50.0
Dilution Gas	996.3	992.7	986.4	980.2	973.9	967.7	955.2	942.7
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

Table S7: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 3

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
CO_2 (ppm)	0	0	250	500	750	1000	1500	2000
N_2O (ppm)	0.330	0.990	0.990	0.990	0.990	0.990	0.990	0.990
Target flows								
Cal 1 / Cal 2	3.7	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Interferent test gas (CO_2)	0.0	0.0	6.3	12.5	18.8	25.0	37.5	50.0
Dilution Gas	996.3	989.0	982.8	976.5	970.3	964.0	951.5	939.0
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments.

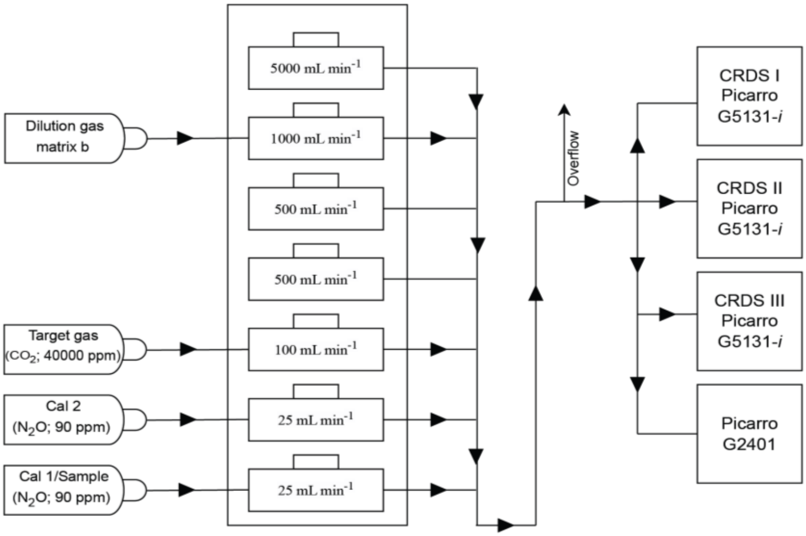

Figure S3: Schematic illustration of the experimental setup used for Exp. 3

S.1.4 O_2 matrix gas effect (Exp. 4)

The experimental setup for Exp. 4 was designed to investigate the effect of O_2 concentrations on apparent δ-values of N_2O. Nitrous oxide target concentrations were set to 0.330, 0.660, and 0.990 ppm, while O_2 were diluted down from ~21 to ~0%, achieved by adjusting calibration and dilution gas flows while maintaining a constant total flow of 1000 mL min^{-1} (Table S8–S10). Each mixture was measured in triplicate across three independent experiments to ensure reproducibility. A schematic of the gas mixing and measurement system is provided in Fig. S4. Please note that the target oxygen concentrations were set at 12, 14, 16, 20, and 20.7%. However, since the *Cal 1* and *Cal 2* reference gases contribute an additional matrix baseline of approximately 770, 1544, and 2316 ppm O_2 at N_2O concentrations of 330, 660, and 990 ppb, respectively, meaning that target O_2 values do not start from zero as they do for N_2O.

Table S8: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 4

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
O_2 (ppm)	770	770	120000	140000	160000	180000	200000	207000
N_2O (ppm)	0.330	0.330	0.330	0.330	0.330	0.330	0.330	0.330
Target flows								
Cal 1 / Cal 2	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Interferent test gas (O_2)	0.0	0.0	572.8	668.3	763.7	859.2	954.7	988.1
Dilution Gas (N_2)	996.3	996.3	423.5	328.1	232.6	137.1	41.7	8.3
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments, and all flows are in mL/min

Table S9: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 4

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
O_2 (ppm)	770	1544	120000	140000	160000	180000	200000	207000
N_2O (ppm)	0.330	0.660	0.660	0.660	0.660	0.660	0.660	0.660
Target flows								
Cal 1 / Cal 2	3.7	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Interferent test gas (O_2)	0.0	0.0	572.8	668.3	763.7	859.2	954.7	988.1
Dilution Gas (N_2)	996.3	992.7	419.9	324.4	228.9	133.5	38.0	4.6
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments, and all flows are in mL/min

Table S10: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 4

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	*Sample 6*	*Sample 7*
Target concentrations								
O_2 (ppm)	770	2316	120000	140000	160000	180000	200000	207000
N_2O (ppm)	0.330	0.990	0.990	0.990	0.990	0.990	0.990	0.990
Target flows								
Cal 1 / Cal 2	3.7	11.0	11.0	11.0	11.0	11.0	11.0	11.0
Interferent test gas (O_2)	0.0	0.0	572.8	668.3	763.7	859.2	954.7	988.1
Dilution Gas (N_2)	996.3	989.0	416.2	320.7	225.3	129.8	34.3	0.9
Total flow	1000	1000	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments, and all flows are in mL/min

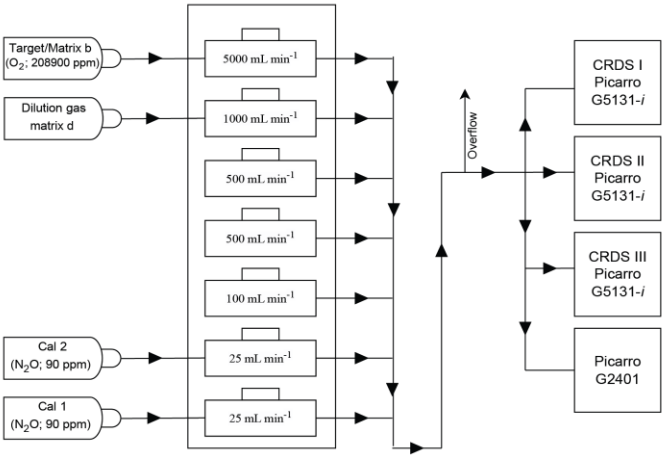

Figure S4: Schematic illustration of the experimental setup used for Exp. 4

S.1.5 Validation experiments to test combined effects of N_2O, CH_4 and CO_2 concentration changes (Exp. 5)

The experimental setup for Exp. 5 was designed to investigate the combined effects of CO_2 and CH_4 on apparent δ-values of N_2O. Nitrous oxide target concentrations were set to 0.330 and 0.660. Carbon dioxide and methane were simultaneously varied from 0 to 2000 ppm and 0 to 10 ppm, respectively, over five steps (Table S11–S12). Each mixture was measured in triplicate across three independent experiments to ensure reproducibility. A schematic of the gas mixing and measurement system is provided in Fig. S5.

Table S11: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–5) Exp. 5a

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*
Target concentrations						
CH_4 (ppm)	0	0	2.5	5	7.5	10
CO_2 (ppm)	0	0	500	1000	1500	2000
N_2O (ppm)	0.330	0.330	0.330	0.330	0.330	0.330
Target flows						
Cal 1 / Cal 2	3.7	3.7	3.7	3.7	3.7	3.7
Interferent test gas (CH_4)	0.0	0.0	12.8	25.6	38.4	51.2
Interferent test gas (CO_2)	0.0	0.0	12.7	25.4	38.0	50.7
Dilution Gas	996.3	996.3	970.9	945.4	919.9	894.4

Total flow	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments, and all flows are in mL/min

Table S12: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–5) in Exp. 5b

Parameter	*Cal 1 / Cal 2*	*Sample 1*	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*
Target concentrations						
CH_4 (ppm)	0	0	2.5	5	7.5	10
CO_2 (ppm)	0	0	500	1000	1500	2000
N_2O (ppm)	0.660	0.660	0.660	0.660	0.660	0.660
Target flows						
Cal 1 / Cal 2	7.3	7.3	7.3	7.3	7.3	7.3
Interferent test gas (CH_4)	0.0	0.0	12.8	25.6	38.4	51.2
Interferent test gas (CO_2)	0.0	0.0	12.7	25.4	38.0	50.7
Dilution Gas	992.6	992.6	967.2	941.7	916.2	890.8
Total flow	1000	1000	1000	1000	1000	1000

Each sample configuration was measured three times in three independent experiments

All flows are in mL/min

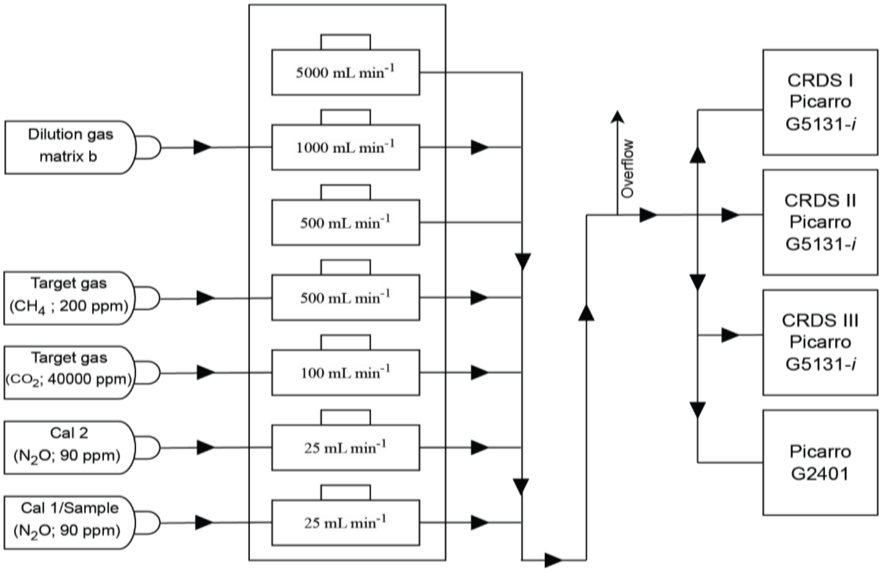

Figure S5: Schematic illustration of the experimental setup used for Exp. 5

S.1.6 Validation of dynamic versus static dilution of reference gases (Exp. 6)

The experimental setup for Exp. 6 was designed to test the difference between dynamic and static dilution of the same reference gas. Nitrous oxide was diluted down to ambient concentrations from a pure N_2O standard (Rm-1-1_{pure}). This was achieved using a custom-built two-step diluter provided by the Swiss National Metrology Institute (METAS), followed by a third dilution step with standalone MFC boxes. A schematic of the gas mixing and measurement system is provided in Fig. S6, while Table S13 provides an overview of the dilution process.

Table S13: Target concentrations and flow settings for calibration and sample mixtures (Samples 1–7) in Exp. 6

Dilution device	Step	RM-1-1_{pure} (N_2O ppm)	Target (N_2O ppm)	Total flow	MFC #1, (RM-1-1_{pure})	MFC #2 (Matrix b)
two-step diluter (Metas)	1.1 (Ch. #1)	1000000	3000	5005	15	4985
	1.2 (Ch. #2)	3000	10	5000	17	4983
MFC (Vögtlin Instruments)	2 (Extra dil.)	10	0.330	500	16.5	483.5

All flows are in mL/min. RM-1-$1_{Diluted-1}$ and RM-1-$1_{Diluted-2}$ have ambient N_2O concentrations and therefore were introduced without dilution. For Cal 1 and 2, both at ~90 ppm, were diluted in a single step using Mixing Chamber 1, identical to the general experimental setup (See for example, Table 2).

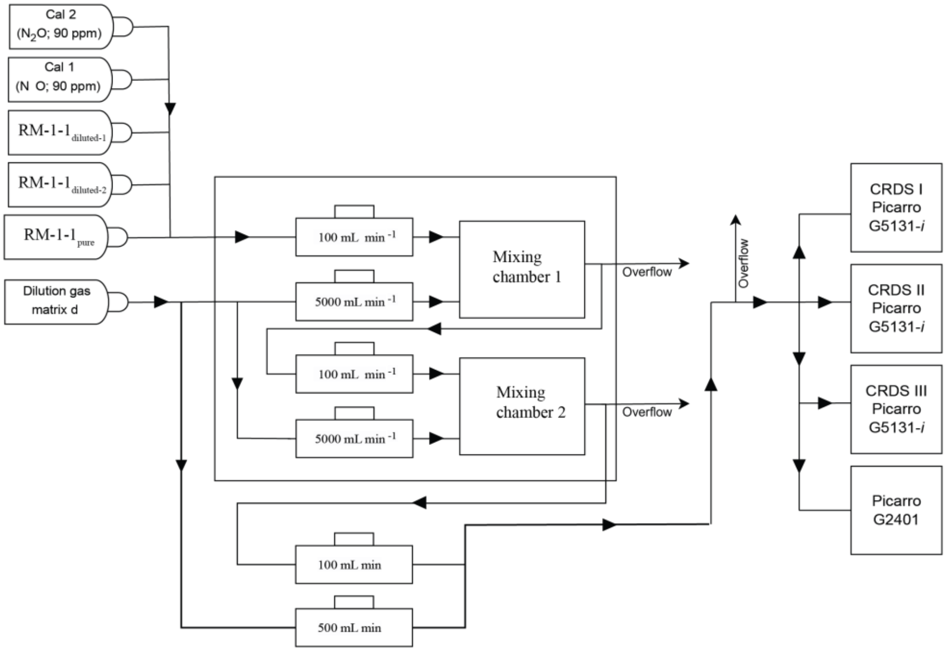

Figure S6: Schematic illustration of the experimental setup used for Exp. 6. RM-1-1$_{Diluted-1}$ and RM-1-1$_{Diluted-2}$ have ambient N_2O concentrations and were therefore routed directly through the system without the use of a dilution gas. Cal 1 and Cal 2 were diluted in a single step in mixing chamber 1, analogous to the general experimental setup, with flow rates as given for example in Table S2. RM-1-1$_{Pure}$ was diluted dynamically to ambient concentrations via the three-step dilution scheme described in Table S13.

S2 Results: dynamic versus static dilution comparison (Exp. 6)

We conducted a study to validate the preparation of statically diluted standards (RM-1-1$_{Diluted-1}$ and RM-1-1$_{Diluted-2}$; Table 1), which might be subject to fractionation effects during preparation, against dynamically prepared gases starting from the same pure N_2O reference gas (RM-1-1$_{Pure}$; Table 1). The key distinction is that RM-1-1$_{pure}$ is an undiluted pure N_2O standard, while RM-1-1$_{Diluted-1}$ and RM-1-1$_{Diluted-2}$ are gravimetrically prepared ambient-concentration dilutions of the same gas (~327; Table 1), which were prepared according to Mohn et al. (2014). The dynamic dilution approach prepares the same gas at ambient concentration in real time using a sequence of dilution steps. To facilitate dynamic dilution from pure gases to ambient concentrations (330 ppb N_2O), i.e. by a factor of 3.3×10^6, a custom-built two-step diluter provided by the Swiss Federal Institute of Metrology (METAS), was applied. Given the very low flows of pure N_2O provided, an extensive stabilisation period of 1 hour was applied, with data from the last 5 minutes used for further analysis. The statically diluted standard gases were measured for of RM-1-$1_{\text{Diluted-1}}$ and Cal $2.1_{330\text{ppb}}$ were bracketing the measuring phase (phase 2). During the measuring phase, each sample gas measurement was bracketed by measurement of the RM-1-$1_{\text{Diluted-1}}$standard gas to continuously assess the analyser's stability and post-correct for any analytical drift.

Results from comparing dynamic versus static dilutions of the same initial pure N_2O gas (RM-1-1_{pure}) show no significant differences between the two approaches (Fig. S7). For $\delta^{15}N^{\alpha}$, both the statically diluted N_2O gas (RM-1-$1_{\text{Diluted-2}}$) and the dynamically diluted N_2O gas (diluted from RM-1-1_{Pure}) fall within the assigned value of -0.22 ± 0.46 ‰ (SD), with RM-1-$1_{\text{Diluted-2}}$ registering at -0.09 ± 1 ‰ (SD) and RM-1-1_{Pure} -0.30 ± 0.9 ‰ (SD). Concerning $\delta^{15}N^{\beta,}$ the statically diluted N_2O gas agrees better with the original pure N_2O, with a value of 0.93 ± 1.2 ‰ (SD) relative to the assigned value of 0.82 ± 0.46 ‰ (SD), while the dynamically diluted N_2O gas displays large variability within -0.97 ± 3.6 ‰ (SD). Lastly, a similar trend is seen for $\delta^{18}O$, where the static dilution approach exhibits a value of 38.94 ± 1.2 ‰ (SD), in line with the assigned value of 39.22 ± 0.15 ‰ (SD), while the dynamic dilution displays a slightly lower number of 38.43 ± 2.7 ‰ (SD). For the dynamically diluted calculations, only data points where the post-processed data had a standard deviation below 8 ‰ were included in the analyses. In summary, no significant offsets in isotopic composition between statically and dynamically prepared ambient concentration N_2O reference gases were detected, which indicates the absence of substantial fractionation effects. Dynamically prepared N_2O reference gases, however, display large variability in N_2O isotopic composition, in particular for $\delta^{15}N^{\beta}$. This effect might not be a fractionation effect, which is supposed to impart all isotopic dimensions, but an apparent effect due to variability in the gas composition (e.g. N_2O concentration), provided the very high dilution ratios. Results also indicate that the applied two-step dynamic dilution is not a suitable approach to provide N_2O reference gases at 330 ppb N_2O at sufficient stability to perform instrument calibration.

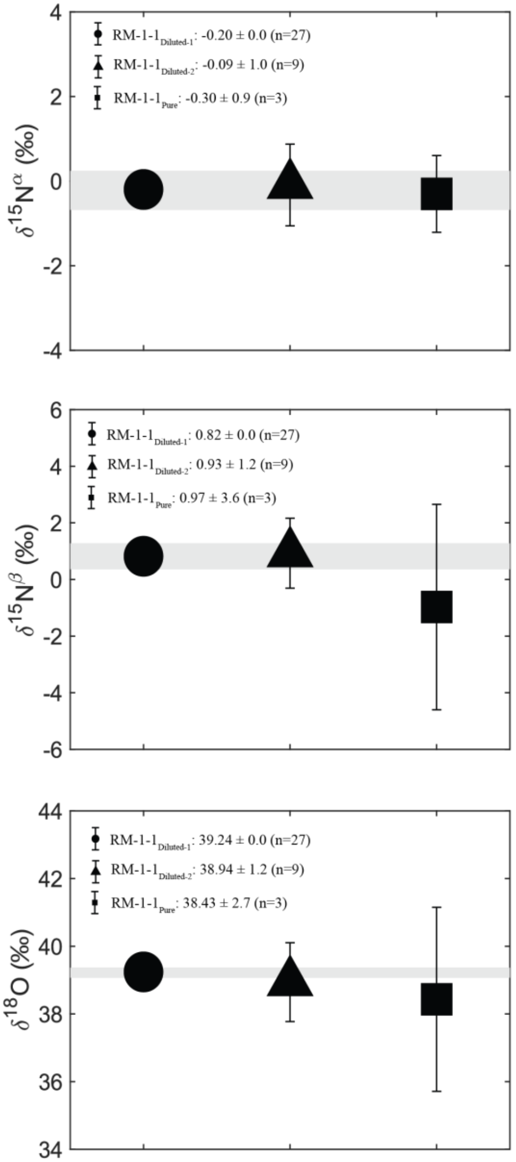

Figure S7: Isotopic composition, $\delta^{15}N^{\alpha}$, $\delta^{15}N^{\beta}$, $\delta^{18}O$ in N_2O reference gases prepared by static dilution (RM-1-1$_{Diluted-2}$) and dynamic dilution from a pure N_2O gas (RM-1-1$_{pure}$) (see Table 1) measured on CRDS II. The grey box represents the isotopic composition ± its uncertainty ($\delta^{15}N^{\alpha}$ = -0.22 ± 0.46 ‰, $\delta^{15}N^{\beta}$ = 0.82 ± 0.46 ‰, $\delta^{18}O$ = 39.22 ± 0.15 ‰) of a statically diluted N_2O reference gas used for comparison (RM-1-1$_{Diluted-1}$).

S3 Uncertainty Evaluation and Error Propagation

S.3.1 Input parameters

Calibration-based measurement models, commonly used for CRDS analysers and similar devices, present the challenge that each applied correction introduces its own inherent uncertainty. To better understand and pinpoint the primary sources of error and gain deeper insight into their influence on the overall measurement uncertainty, we conducted an uncertainty evaluation using the error propagation of up to 7 parameters per delta value. These parameters include the regression slopes (m_{N2O}, m_{CH4}, m_{CO2}) used for the trace gas-related corrections (N_2O, CH_4 and CO_2), the δ-values of the applied isotopic reference gases, and an additional term due to poorly-understood effects, related to instrumental drifts and other uncharacterised aspects of the measurement system. This could be expressed by the standard deviation of repeated target gas analyses. The uncertainties were evaluated using the GUM guideline (BIPM et al., 2008; JCGM, 2008) and using the law of propagation of uncertainty to yield the combined standard uncertainty

$$\sigma^2\left(f(x_i)\right) = \sum_{i=1}^{N}\left(\sigma^2(x_i) * \left(\frac{\partial f}{\partial x_i}\right)^2\right) * u^2(x_i)$$

Where f is the mathematical model reported in Appendix A, x_i is the input quantity, and$u(x_i)$ the uncertainty of each of the input variables. The partial derivatives are provided in Appendix A and describe how sensitive the measurand responds to changes in a given input variable. In the implemented error analysis, we anticipate that the applied mathematical measurement model is correct, i.e. correction terms are additive and constant in time. As spectral interferences were observed to be non-additive and the N_2O non-linearity was found to be variable in time (see Section 3), the uncertainty evaluation implemented in the MATLAB code is only valid for a best case and should be taken with care.

S.3.2 Example of uncertainty budget

To provide an exemplary uncertainty estimate, we evaluated the uncertainty components for experiment 2 (sec. 3.2) performed at 330 ppb N_2O (Cal-1) with different additions in CH_4 (up to 10 ppm). In detail, measurements on 05.02.2024 with CRDS-I were evaluated. The following input parameters for the uncertainty calculations were considered; the uncertainties in the N_2O non-linearity correction slope (Δm_{N2O}), the CH_4 correction slope (Δm_{CH4}), and the isotopic composition of $Cal_{1.1}$ and $Cal_{2.1}$ reference gases, provided in Tables 4, 5, and 1, respectively. The uncertainty contribution by the N_2O concentration correction (Eq. A20) is negligible for all delta values (< 0.01 ‰), since sample and reference gases are measured at similar N_2O

concentration (330 ppb). The uncertainty due to "imperfect" CH_4 spectral interference correction (Eq. A21) increases with increasing CH_4 concentration, up to 0.23 ‰ in $\delta^{15}N^{\alpha}$, 0.13 ‰ in $\delta^{15}N^{\beta}$ and 0.05 ‰ in $\delta^{18}O$ for the highest CH_4 sample (10 ppm). The propagated uncertainty due to the calibration correction (Eq. A23-A24) is approximately 0.31 ‰ in $\delta^{15}N^{\alpha}$, 0.11 ‰ in $\delta^{15}N^{\beta}$, and 0.35 ‰ in $\delta^{18}O$. The uncertainty due to poorly understood effects, estimated by the repeatability of target gas measurements, is 0.5 ‰ for all isotopologues. The total uncertainties (Eq. A19) for the N_2O sample gas with 10 ppm CH_4 sample are 0.63 ‰, 0.53 ‰, 0.62 ‰ for$\delta^{15}N^{\alpha}$, $\delta^{15}N^{\beta}$ and $\delta^{18}O$, respectively.

References

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