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Improvements to Picarro's G2401 and G2301 – ICOS-Compliant Reproducibility, and Improved Drift Specifications in Response to Results from ICOS Instrument Comparison

Graham Leggett*, Alejandro Farinas, Eric Lai, Anders Nottrott, Jorge Perez, Chris Rella, Sze Tan, Scott Yasuhara*
Picarro, Inc., 3105 Patrick Henry Drive, Santa Clara, CA 95054, USA

Introduction

In a paper published by the Integrated Carbon Observation System (ICOS), the drift performance of 47 Picarro analyzers of 3 different generations were compared (Yver Kowk et al, Atmos. Meas. Tech. Discuss., 8, 4219–4272, 2015). The results are summarized in Figure 1. The results show that methane drift (the minimum of the Allan standard deviation) was much better in first-generation G1000 analyzers. Our initial assessment concluded that the source of the drift is the pressure sensor system.

In parallel with this investigation, and in response to demanding ICOS specifications for reproducibility for CO measurements, we implemented software and hardware updates resulting in our standard production G2401 analyzer exceeding these requirements.

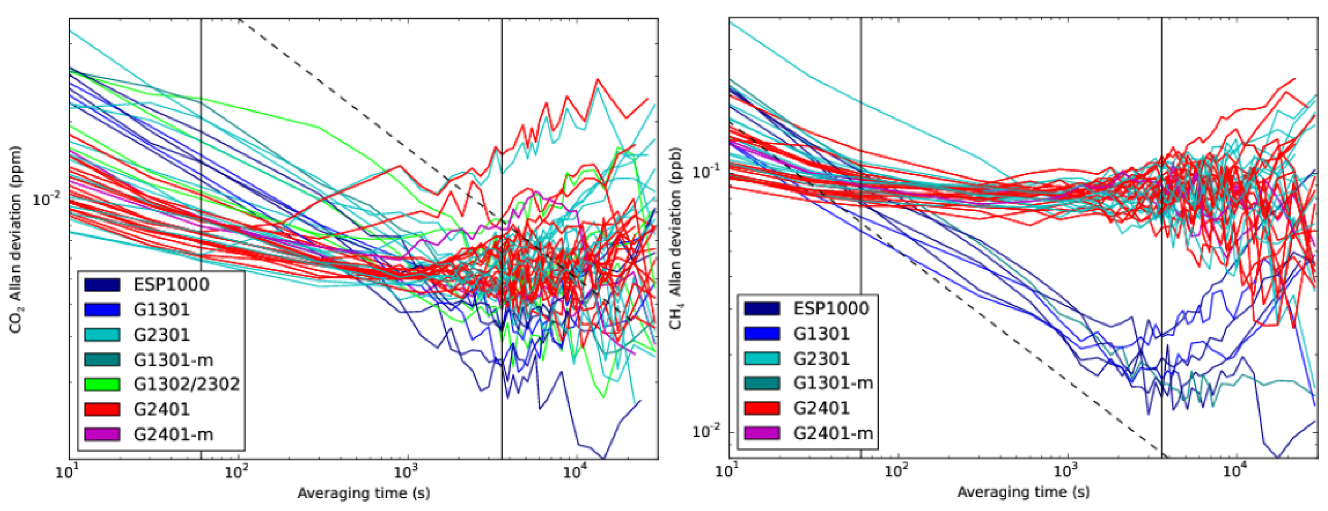

Figure 1. *Allan standard deviations of 47 Picarro CO_2 and CH_4 analyzers.*

Analyzer Drift – Preliminary Assessment

In first considering the observed drift, it was proposed that the pressure sensor system could be the source of this effect. We considered the ratio of the Allan standard deviation minimum for CO_2 an CH_4:

$$\left.\frac{\sigma_{CO_2}}{CO_2}\right|_{min} = \frac{7\text{ ppb}}{380\text{ ppm}} = 1.8\times10^{-5}$$
$$\left.\frac{\sigma_{CH_4}}{CH_4}\right|_{min} = \frac{90\text{ ppt}}{1.8\text{ ppb}} = 5.0\times10^{-5}$$

The ratio of the CH_4 to the CO_2 minimum is 5/1.8 = 2.78. This is very close to the ratio of drift if the source of the drift is the pressure.

$$\frac{\partial f_{CO_2}}{\partial P} = 1.3\times10^{-3}\text{ Torr}^{-1}$$
$$\frac{\partial f_{CH_4}}{\partial P} = 3.5\times10^{-3}\text{ Torr}^{-1}$$

The ratio of the CH_4 to the CO_2 pressure dependence is 3.5/1.3 = 2.69. Temperature, wavelength, and loss-measurement drifts would have a very different dependence. The pressure sensor itself did not change between G1000 and G2000, but the measurement electronics in our system did. The next step was to analyze the electronics.

Analysis of Pressure Drift

A simplified schematic for the pressure measurement circuit is shown in Figure 2. The pressure sensor is a MEMS piezoresistive gage fabricated in a Wheatstone bridge configuration. The bridge is biased by a constant-current source, I_0, and read out with a discrete-component instrumentation amplifier; U1, U2, and U3. The output of the instrumentation amplifier is digitized in an ADC, U4.

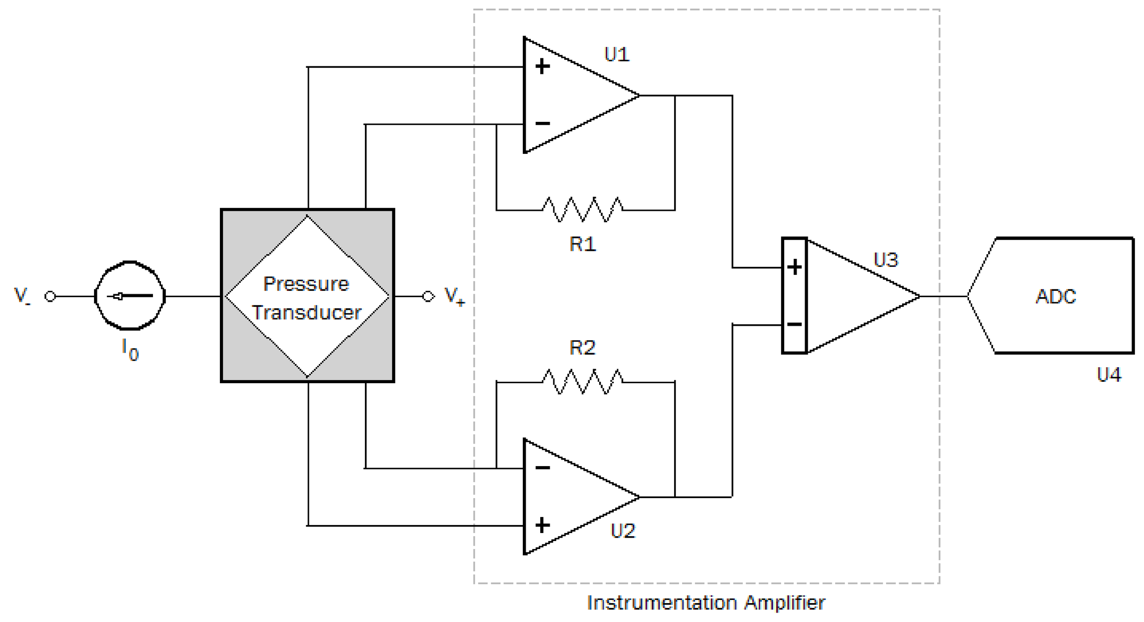

Figure 2. *Pressure measurement electronics.*

The readout of the ADC, *M*, for a given real pressure, *P*, is

$$\frac{M}{2^N-1} = \frac{A_{diff}k_{trans}I_0P}{V_{ref}}$$

where; *N* is the number of bits of the ADC, A_{diff} is the differential-mode gain of the instrumentation amplifier, k_{trans} is the transducer's conversion gain (in V Torr^{-1} A^{-1}), and V_{ref} is the voltage reference provided to the ADC. If the input offset voltage of the op-amps, V_{OS}, is included, the relation becomes

$$\frac{M}{2^N-1} = \frac{A_{diff}k_{trans}I_0P + V_{OS_{diff}}A_{diff} + V_{OS_{ADC}}}{V_{ref}}$$

Solving for the real pressure yields

$$P = \frac{\frac{M}{2^N-1}V_{ref} - V_{OS_{diff}}A_{diff} - V_{OS_{ADC}}}{A_{diff}k_{trans}I_0}$$

To first order, drift in these parameters would cause a change in pressure given by

$$\frac{\Delta P}{P_{set}} \approx \frac{\Delta V_{ref}}{V_{ref}}$$
$$\frac{\Delta P}{P_{set}} \approx \frac{\Delta I_0}{I_0}$$
$$\frac{\Delta P}{P_{set}} \approx \frac{\Delta A_{diff}}{A_{diff}}$$
$$\Delta P \approx \frac{\Delta V_{OS_{diff}}}{k_{trans}I_0}$$
$$\Delta P \approx \frac{\Delta V_{OS_{ADC}}}{A_{diff}k_{trans}I_0}$$

where P_{set} is nominal setpoint of the pressure feedback loop

$$P_{set} = \frac{M}{2^N-1}\frac{V_{ref}}{A_{diff}k_{trans}I_0}$$

The results of an analysis of the specific components on the circuit boards revealed the critical components to be the resistors that determine I_0 and the op-amps U1 and U2. By changing from 1 % to 5 % resistors in the G2000, the pressure drift increased by a factor of five. Even worse was the change in the op-amp which increased drift by a factor of 25. By changing these components the drift was predicted to reduce back to G1000 levels, or better.

In order to validate the predictions of the circuit analysis, modified pressure sensor boards were constructed and tested.

Two production G2000 analyzers were first characterized with stock pressure sensor boards, then with the upgraded boards. Allan standard deviations were plotted from 3 days of continuous measurements of the same gas cylinder filled with synthetic air. The results of these experiments are shown in Figures 3 and 4. The Allan standard deviation for the unmodified board reproduce ICOS's results quite closely. The upgraded boards show the expected improvement in CH_4 averaging.

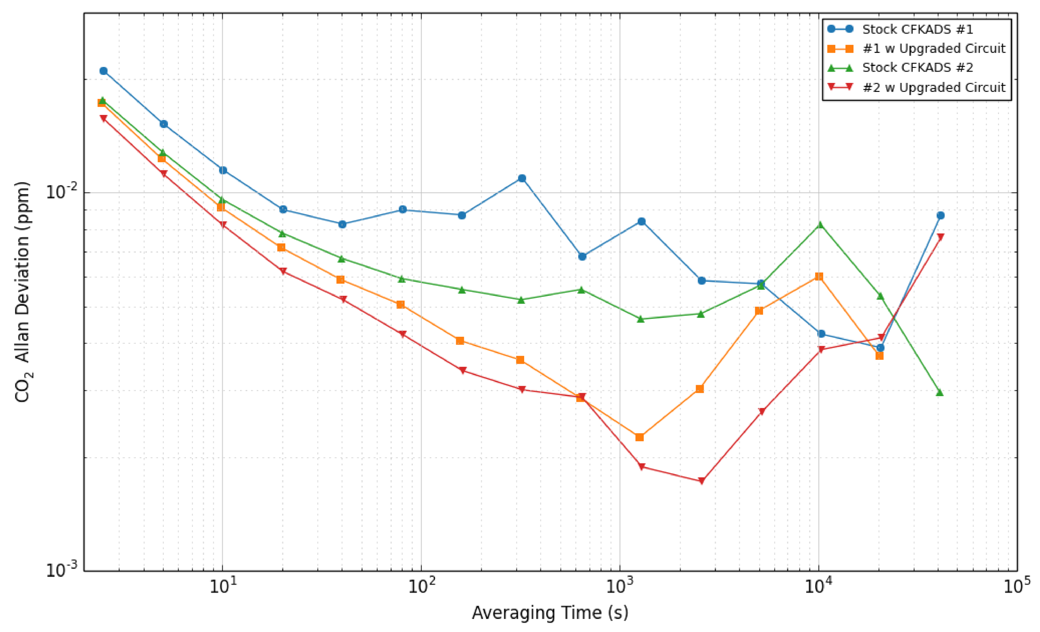

Figure 3. Allan standard deviation of CO_2 concentration.

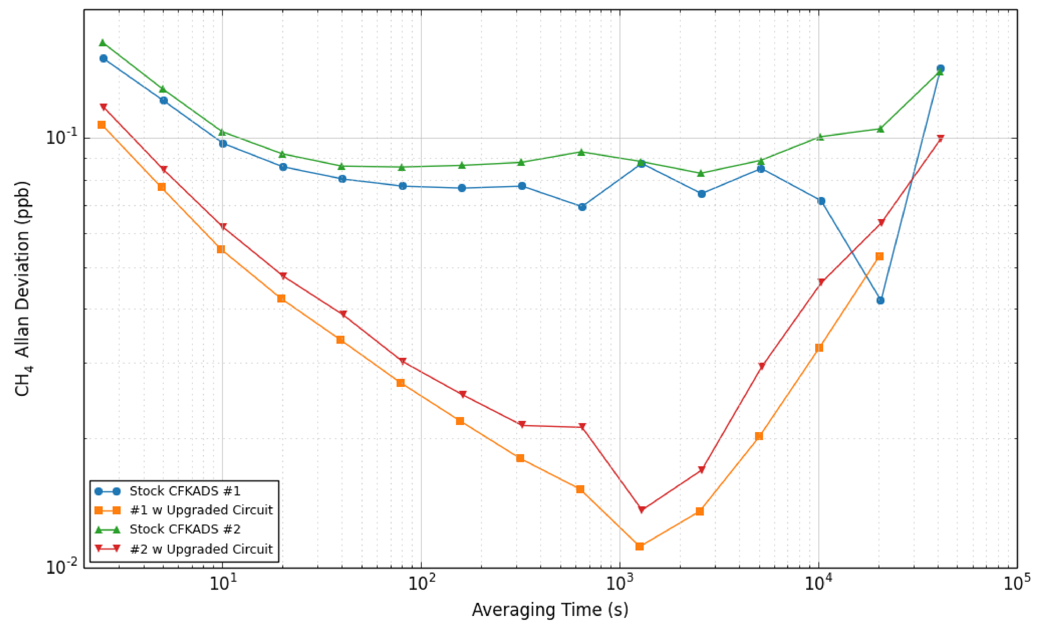

Figure 4. Allan standard deviation of CH_4 concentration.

ICOS CO Reproducibility Specifications

Following an exhaustive review of recent production instruments and key performance characteristics, our published specifications have been updated to reflect general ICOS and GAW compliance.

Guaranteed Performance Specifications *in dry air*	**CO_2**	**CO**	**CH_4**	**H_2O**
Precision (5 sec / 5 min / 60 min, 1σ) *Reference gas not needed*	< 50 ppb / 20 ppb / 10 ppb	< 15 ppb / 1.5 ppb / 1 ppb	< 1 ppb / 0.5 ppb / 0.3 ppb	< 30 ppm / 5 ppm / n/a
Max Drift at STP (over 24 hrs / 1 month) (peak-to-peak, 50-minute average) *Reference gas not needed*	100 ppb / 500 ppb	10 ppb / 50 ppb	1 ppb / 3 ppb	100 ppm ± 5% of reading
Max Uncertainty using Reference Gas (1 hr average, 2σ) *WMO Data Quality Objective for GAW Stations*	< 50 ppb	< 2 ppb	< 1 ppb	n/a
Reproducibility (10 min, 1σ) [1] *ICOS Atmospheric Station Specification*	< 50 ppb	< 1 ppb	< 0.5 ppb	n/a
Automated Determination of Dry Mol Fraction	Included	Included	Included	n/a
Operating Range	0 – 1000 ppm	0 – 5 ppm	0 – 20 ppm	0 - 7 %v H_2O
Guaranteed Specifications Range	300 – 500 ppm	0 – 1 ppm	1 – 3 ppm	0 - 3 %v H_2O
Measurement Interval	< 5 seconds	< 5 seconds	< 5 seconds	< 5 seconds
Rise/Fall time (10 - 90 % / 90 - 10%)	< 5 seconds	< 5 seconds	< 5 seconds	< 5 seconds

Conclusions

The degradation of G2000 CH_4 drift performance measured by ICOS was determined to be due to the increased temperature sensitivity in the pressure sensor preamp. Changing to 0.1 % resistors and an alternative amplifier results in a restoration of performance to G1000 levels. In light of this analysis corrective action was taken immediately and G2000 units are now fitted with the alternative components. In addition, a review of recent, historical performance data has resulted in the publication of revised, improved specifications for our G2401.

Interested in learning more?

- Stop by the Picarro booth for a demonstration of the G2401
- Contact Graham Leggett (gleggett@picarro.com)
- Visit www.picarro.com