Evaluation of low-cost CO2 sensors to study atmospheric mixing in a mountain valley

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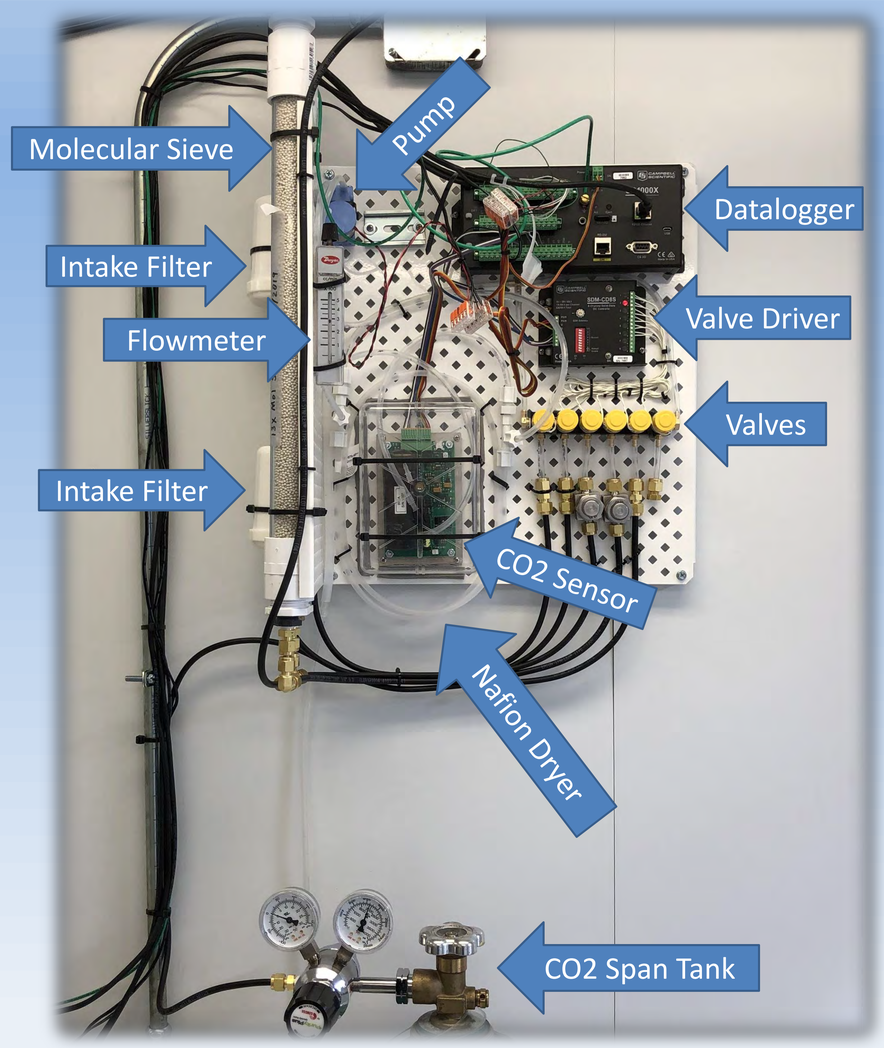
Abstract

Air pollutants are trapped in mountain valleys during persistent cold-air pool events, when atmospheric mixing is suppressed. We are developing a network of weather stations using CO2 as a tracer gas to study atmospheric mixing in Cache Valley, Utah. An initial deployment of five relatively low-cost open-path sensors (Vaisala, GMP343, ~$3000) has a significant temperature sensitivity, which confounds the diel CO2 cycles we seek to understand. We have thus begun testing a lower-cost closed-path sensor (PP Systems, SBA-5, ~$1600). The parts cost of a complete system, including analyzer, pump, solenoid valves, etc. is comparable to the open-path sensor, and it allows automated zero and span, and the measurement of vertical CO2 profiles. Laboratory testing shows promising performance. Allan deviation shows their precision to be 0.2 to 0.4 ppm, for averaging times from 10 s to one hour. Their precision is dominated by offset error, which drifts -1 to -10 ppm per day, and is subject to random (~monthly) events in which the reading increases by up to 100 ppm over a few hours. Their span is quite stable. After resetting the instrument zero, the CO2 span factor repeatability is 0.2%. The first of these sensors is now deployed in a system that automatically sets the zero and span.

Field System

First system deployed at Smithfield DAQ site on 12 Mar 2019.



CO2 Sensor

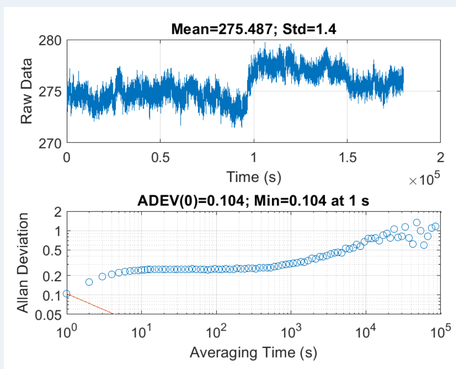
PP Systems model SBA-5
CO2 Range: 0 – 1000 ppm
Pressure Compensation: 60 – 115 kPa
Accuracy: < 1%
Linearity: <1%
Measurement rate: 10 Hz
Power Consumption: 1-3 W nominal
Dimensions: 12 x 3.5 x 7.5 cm

Precision

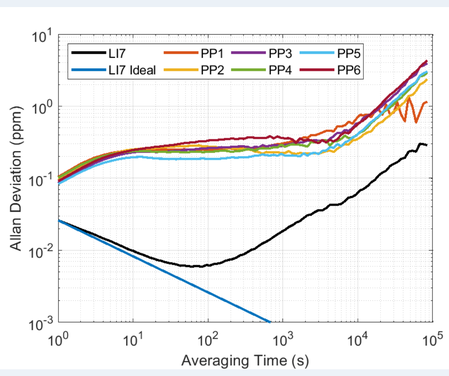
The precision of six sensors was tested by sampling air from a tank of compressed air at 1 Hz over 50 hours. A LI-COR LI-7000 analyzer was included for comparison. Allan deviation analysis shows their precision to be 0.2 to 0.4 ppm, for averaging times from 10 s to one hour. This suggests a one hour interval between zero/span sequences is optimal.

Initial Field Performance

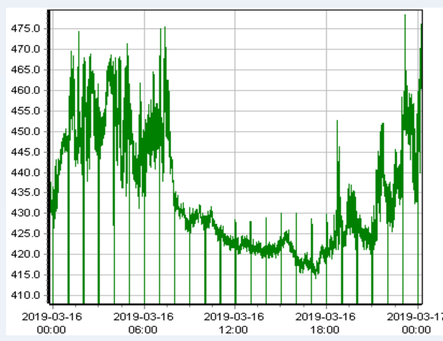
Example time series and Allan deviation



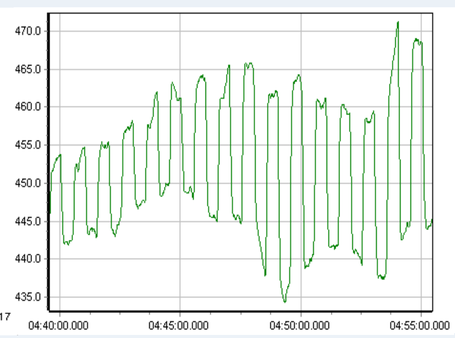
Allan deviation comparison



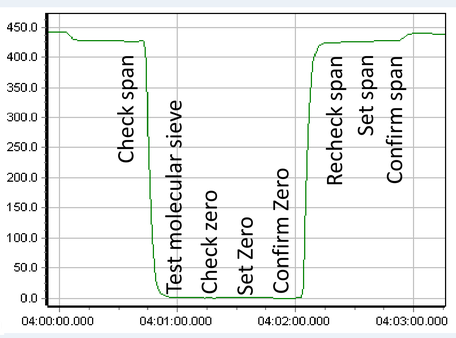
24 hour CO2 time series



Switching upper/lower intakes



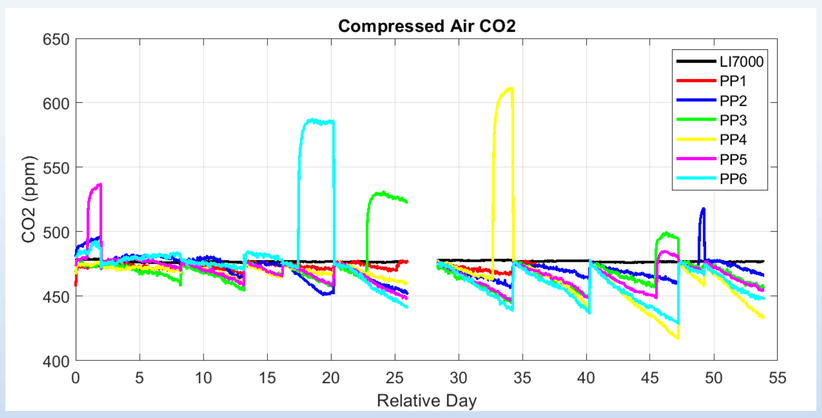
Hourly zero/span sequence

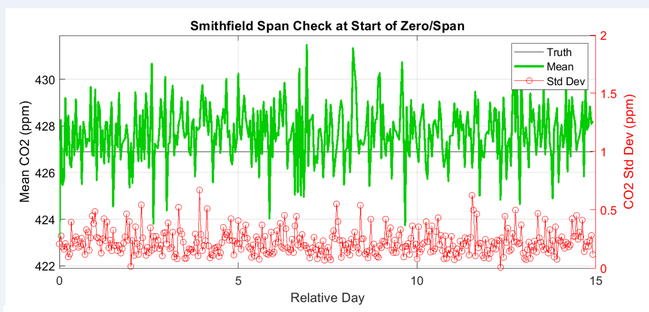


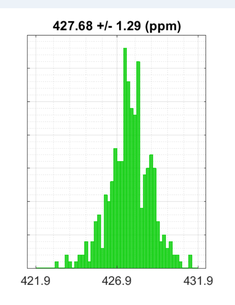
Zero/span stability

Six SBA-5 sensors were run in the laboratory for 54 days, cycling between zero air, a tank of compressed air, and outside air. Their CO2 measurements were compared to a reference instrument measuring the same air (LI-7000). The CO2 zero and span were manually set nine times during the test.

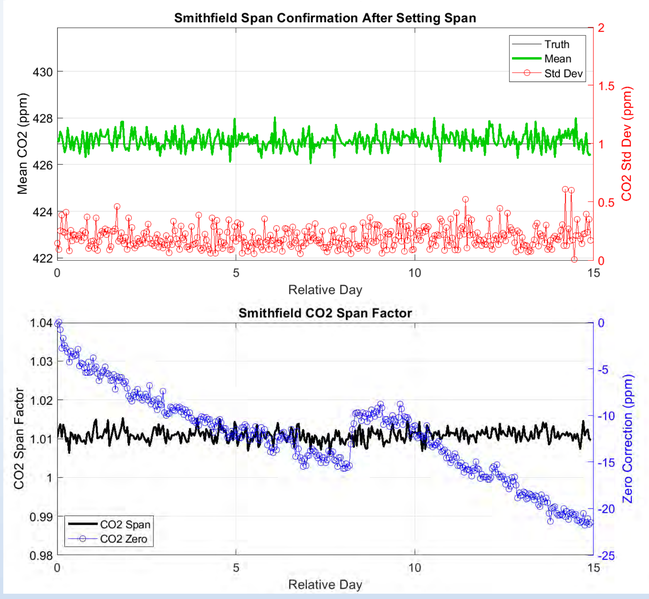
Hourly measurement of CO2 in compressed air

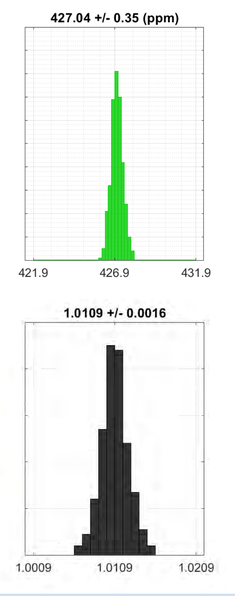




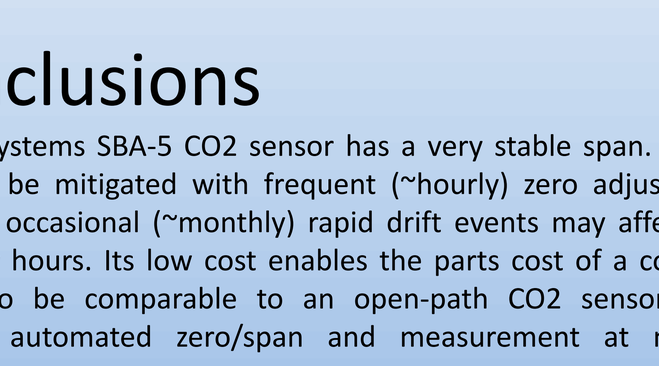


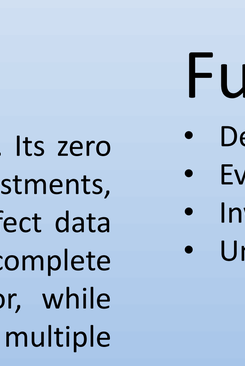
Check span before setting
- Bias: 0.78 (ppm)
- Standard deviation: 1.29 (ppm)





Confirm span after setting
- Bias: 0.14 (ppm)
- Standard deviation: 0.35 (ppm)





Span correction factor
- 1.0109 +/- 0.0016

Zero correction
- ~-2 ppm/day
- One small rapid drift event observed in 15 days

Zero stability
- Zero was more stable during the first ~2 weeks
- The ultimate zero drift rate ranged from -1 to -10 ppm/day
- Rapid drift events occurred every 43 days on average, changing up to 100 ppm in a few hours

Span stability
- Span standard deviation: 0.27 to 0.39 %

Conclusions

The PP Systems SBA-5 CO2 sensor has a very stable span. Its zero drift can be mitigated with frequent (~hourly) zero adjustments, although occasional (~monthly) rapid drift events may affect data for a few hours. Its low cost enables the parts cost of a complete system to be comparable to an open-path CO2 sensor, while allowing automated zero/span and measurement at multiple heights.

Future Work

- Deploy additional systems
- Evaluate pressure and temperature effects
- Investigate equilibration at valve switching
- Uncertainty analysis