Vertical Profiles of Greenhouse Gas Concentrations via Airborne Measurements

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Abstract

Airborne greenhouse gas (GHG)measurements provide essential constraints for estimating surface emissions. Until recently, dedicated research-grade instruments have been required for this purpose. Here, we report an airborne greenhouse gas analyzer capable of accurate CO_2, CH_4, and H_2O mixing ratio measurements made during two collaborative flight campaigns. First, vertical profiles were flown to ~ 8 km amsl using a Cessna 210 aircraft over Briggsdale, Colorado. Second, a set of regional surveys with another Cessna 210 over Central California quantified enhancements in CO_2 and CH_4 from urban and agricultural sources. Flask samples, collected during all flight, are used to demonstrate that analyzer drift over time and as functions of changing cabin pressure (625 -270 Torr) and temperature (15 – 26ºC), remained within performance specifications.

Motivation

Capability for continuous, accurate, in-situ airborne greenhouse gas (GHG) measurements are valuable for:

- Estimating time-varying vertical and horizontal atmospheric structures and mixing rates
- Validating satellite and ground-based remotely sensed GHG columns
- Quantifying local to regional GHG enhancements for emissions inventory verification

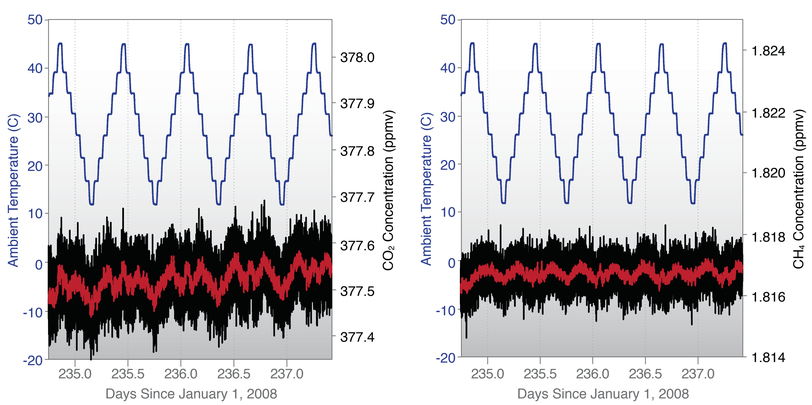
Until recently, no commercially available technologies combined adequate absolute accuracy with sufficient ease-of-use for routine airborne observations.

Measured In-Flight Performance

Specification	Measurements
CO_2 Precision	40 ppbv
CH_4 Precision	0.3 ppbv
H_2O Precision	50 ppmv
Measurement Interval	2 seconds
Drift (20 hours)	150 ppbv
Avionics Bay Temp Range	20-40C
Avionics Bay Pressure Range	250-1000 mbar
Sample Pressure Range	220-1050 mbar

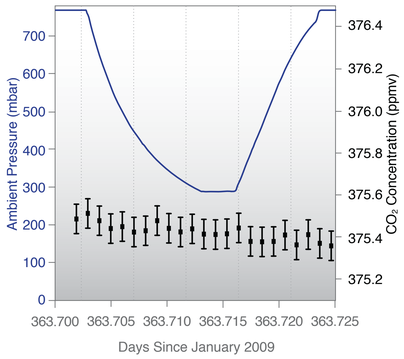
Ambient Temperature Test

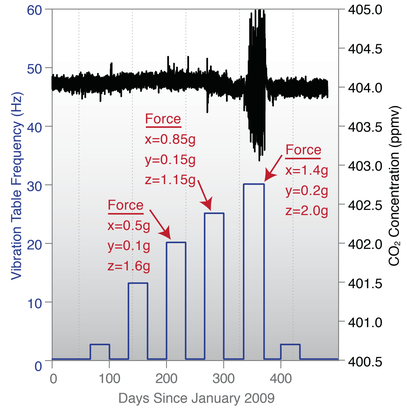
Using an environmental chamber, the flight analyzer underwent an extensive series of ambient temperature tests. The line shown in red is a two minute average of the 2 second concentration measurements. Results indicate that the temperature sensitivity while ramping the ambient temperature from 10ºC to 45ºC was 1.1 ppbv/C for CO_2 and 0.003 ppbv/C for CH_4. No significant hysteresis effects were seen.



Pressure Chamber Test

Picarro built an atmospheric chamber for testing the flight analyzer in which the pressure inside the chamber as well as the sample delivery system can be quickly and independently varied from 1000 Torr down to 10 Torr. In this test, both the ambient pressure and the sample inlet pressure was varied while the analyzer was continuously measuring CO_2 and CH_4 flowing from a gas bottle.





Vibration Table Test

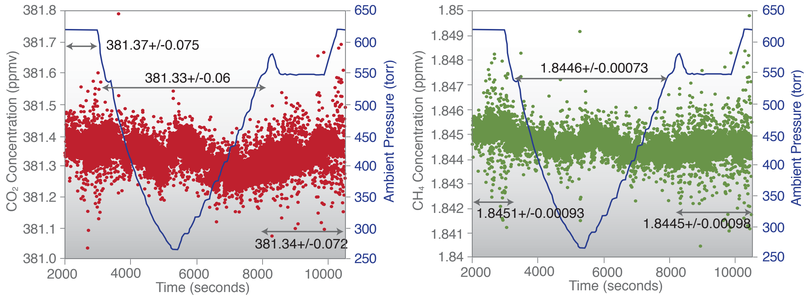
The analyzer was placed on the vibration table while continuously sampling from a gas bottle containing 404 ppm of CO_2. The precision and accuracy of the analyzer remained constant at frequencies and forces below 20Hz and 1g. At 25Hz some degradation in the accuracy of the analyzer is seen. At a frequency of 30Hz and forces in excess of 1 g, the precision of the analyzer degrades substantially. Mechanical noise in the flow control valves caused the analyzer to have difficulty properly regulating the pressure in the cavity. Changes as large as ±1 Torr in cavity pressure were seen.

Results from Flight Testing

Picarro in collaboration with researchers at NOAA in Boulder, CO executed on a performance assessment of the prototype analyzer by flying the analyzer aboard a NOAA Cessna 210 aircraft over Briggsdale, CO. In addition, Picarro in collaboration with researchers at Lawrence Berkley Laboratory and NOAA executed on nine flights aboard a Cessna 210 taking CO_2 and CH_4 profiles over northern California. All flights included CO_2, CH_4, and H_2O profiles taken during take-off, landings, and level flight. Flasks were taken at random intervals to help quantify analyzer drift over ambient pressure, temperature, and time. The aircraft reached altitudes in excess of 25,000 ft with the analyzer located in an unpressurized cabin where temperature changed by greater than10ºC.

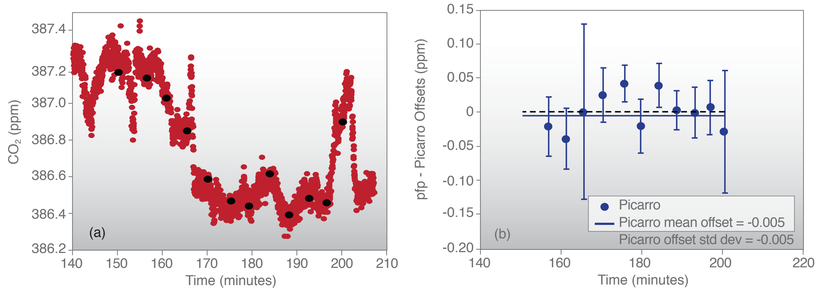
NOAA Cessna 210 aircraft measurements over Briggsdale, CO

The data shown below was taken while the analyzer was sampling from gas bottles containing mixtures of CO_2 and CH_4 and while both the ambient pressure and the sample inlet pressure were changing over the duration of the flight. The lines shown in blue are continuous ambient pressure measurements while in flight (250 Torr corresponds to an altitude of approximately 8 km). The variation in CO_2 measurements, over the course of the flight, was less than 0.1 ppm while the variation in CH_4 measurements was less than 1 ppb.



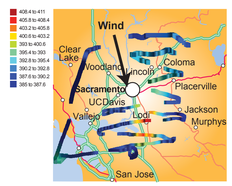
Comparison with Flask Measurements

A comparison of analyzer measurements taken while continuously sampling ambient air at a 0.5 Hz rate with flask measurements taken approximately every five minutes while flying over Briggsdale, CO is shown in the figure (a). The analyzer data was corrected using a single gas standard that was run through the analyzer before and after the time trace shown. The time trace is an altitude profile to 25000 feet (first flask at 25k ft, and so on down). The difference between each flask measurement compared with prototype measurements using a 10-second linearly weighted average of the 0.5 Hz data is shown in figure (b). The mean offset between the prototype data and flask measurements was -0.005 ppm (which was really quite remarkable). Over three flights (not including the data shown below), the bias in the results was -0.06 ppm for CO_2 and 0.4 for CH_4 and the standard deviation of offsets was 0.19 ppm for CO_2 and 2.2 ppb for CH_4.



Flights over Northern California

Carbon dioxide measurements over Sacramento, CA measured in a Cessna 210 on February 27, 2009. The 20 ppm gradient of CO_2 which peaks just down wind of Sacramento is a good example of the type of what an aircraft analyzer is capable of measuring. These measurements combined with back trajectory models will allow estimates of urban area CO_2 emissions.



Summary of Results

The objective of this program was to fill a crucial instrumentation gap by developing a rugged, turnkey flight analyzer suitable for research aircraft deployment that will enable a massive increase in the quantity and quality of air-borne data, specifically measurements of CH_4, CO_2 and H_2O spanning altitudes from <100 m to 10,000 m. To this end, the flight analyzer's performance was found to be very satisfactory both in laboratory testing and while flying on several missions. In addition, vibration sensitivity measurements made in the laboratory and while flying were very encouraging and indicated that vibration related performance should be tractable.