

## ***Interactive comment on “A multi-year record of airborne CO<sub>2</sub> observations in the US Southern Great Plains” by S. C. Biraud et al.***

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### 1. General comments:

Reviewers' comment: The authors state in section 2.5 that “the use of multiple technologies...allowed detection and diagnostics of problems in all parts of the system”. Details of those problems would be particularly useful to other researchers in the field and would be very appropriate for AMT.

Authors' response: During early phases of our program (prior 2007) when RM0 was the only continuous analyzer on board the platform, there were discrepancies continuous and flask-based observations. We determined that the commercial membrane drier of

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the analyzer had developed leaks and was not robust enough for the airborne platform. A custom membrane drier was constructed that solved the problem. Later, we found that the original second stage of drying by chemical cartridge (Magnesium perchlorate) could not support the targeted maintenance schedule of 80 flight missions, each lasting at least three hours and sometimes originating in hot humid conditions. The remedy was to develop a small reusable cartridge of the same material that could be replaced by the pilot in minutes without significant manipulation of the analyzer's enclosure. Maintenance is scheduled every 10 missions during the hot humid months and 15 missions otherwise. After this upgrade, the flask and analyzer technologies gave comparable mean concentrations. Early in our program, RM0 observations displayed substantial fluctuations in CO<sub>2</sub> concentrations even in the free troposphere at constant altitude. Because the analyzer has solid state cells and has negligible sensitivity to motion of the platform, we predicted that these fluctuations were real. This hypothesis was verified by the addition of a second continuous analyzer (RM12) that had an intentional smaller lag of 15 sec. It was shown that the fluctuations did indeed have the proper difference in lag expected for an atmospheric origin. Various kinds of artifacts (e.g., platform power supply fluctuations, and motion sensitivity) should happen simultaneously with differential lag of zero between the analyzers. No such correlations were observed. The integration of the RM12 provided an expanded set of validations consisting of the double-blind comparison between each analyzer and the flask technology and a new form, phased Broadband Validation. It can be used to validate the fast fluctuations and transients originating from the atmosphere, not just the mean absolute levels provided by the comparison with the flasks.

In response to the reviewer comment, we have added the following text to section 2.5 of the paper: “The use of multiple technologies on the ACME platform (i.e., broadband validation) is important, because of the large changes in ambient humidity, pressure, and temperature that the platform experiences during a flight. Mean absolute concentrations measured by a continuous analyzer are validated by comparison with flask observations. An additional level of validation is made by comparing continuous

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observations to each other, one analyzer having an intentional lag of 15 seconds with respect to the other one. Atmospheric fluctuations must be detected by both analyzers, one analyzer's response to these fluctuations lagging the other analyzer's response by 15 seconds. Any fluctuations happening simultaneously or with some other differential lags in both analyzers must be viewed as artifacts. This approach has improved objectivity of the airborne platform substantially by allowing detection and diagnostics of problems in all parts of the system: leaks in the flask sampler compressor package, drift in calibration cylinders used by the continuous analyzers, and aging of the inlet tubing."

Reviewers' comment: Section 2.4 mentions a flask storage effect which has not been corrected for but which may lead to a bias of 0.2 ppm. Can you be more definitive about this bias, or apply a correction? If a 0.2 ppm bias exists, this by itself exceeds the <0.1 ppm difference claimed in the abstract.

Authors' response: The storage bias of 0.2 ppm is acknowledged by NOAA/ESRL on their website (<http://www.esrl.noaa.gov/gmd/ccgg/aircraft/qc.html>). It was decided by NOAA that flask-based observations will be presented without correction. This potential issue has to be investigated and resolved by NOAA. In part, this publication serves to publicize the value of validation by flask technology and the need to understand its performance to 0.10 ppm accuracy. In response to the reviewer comment, we have separated the claims of agreement between the technologies, analyzer versus analyzer, and analyzer versus flask.

Reviewers' comment: The strategy of comparing data from two continuous analyzers, but with an intentional 15 s delay in one analyzer, is an interesting one. What did you learn from this? Can you provide examples of any effects that were identified by this strategy?

Authors' response: This was an innovation of our study. We believe that this is a gateway to being able to objectively isolate many kinds of artifacts on the difficult airborne

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platform. See authors' response to the reviewer's first comment for examples.

Reviewers' comment: There are several data sets assessed in terms of the RM0-RM12 difference, which yield a range of results > 0.1 ppm. Section 2.4 describes an onboard cylinder test where  $RM0-RM12 = 0.19$ . Section 2.5 quotes a difference of -0.08 ppm for 37 flights in 2011. Figures 4 and 7 show data from individual flights with small mean differences but systematic differences of up to several tenths of a ppm during each flight. Can you comment on what might be causing the in-flight variability? Is this a typical or regular feature?

Authors' response: The mean errors in RM0-RM12 reflect the cumulative effects of the multiple sources of error at different time scales (integration time, differential zero and responsivity changes during flight, absolute calibration of the reference cylinders, calibration using WMO scale, correction for NDIR non linearity, drying system performance ...). As shown in the paper, we have developed a strategy to better quantify these mean errors, and a follow-up paper describing and quantify these errors is in preparation. The latest set of deployments (performed after this manuscript was submitted and thus not included in the manuscript), totaling 32 additional missions as of Dec 16, 2012, is showing a mean RM0-RM12 difference value of  $0.11 \pm 0.01$  ppm during descent (uncertainty is the one standard deviation of the mean). The corresponding peak-to-peak uncertainty in the RM0-RM12 difference is 0.20 ppm. The typical RMS noise for the time series of RM0-RM12 for each of the twelve levels of the descent is 0.18 ppm, a value consistent with the individual noises of the analyzers.

Reviewers' comment: Figure 6b shows a mean RM0-flask difference above 3500 m altitude of 0.22 ppm averaged over 480 points, with a standard error of only 0.02 ppm. I would view this as strong evidence of an altitude-dependent difference between techniques. This should be examined further. The presence of larger differences or artifacts should not preclude publication. The measurements are not straightforward and it may not be possible to explain the causes, but I think it's important that these items are acknowledged and discussed.

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Authors' response: We plan to write a follow-up paper where we will quantify in a systematic way, all biases that are affecting our airborne observations, and in particular errors associated with the flask package. We believe flask validation alone is not sufficient and that phased broadband validation is a robust way to validate airborne observations.

## 2. Technical corrections:

- 7188, line 20 – The term “broadband validation” has been replaced in the abstract by “multiple technologies”, and is better defined later in the methods section. The following section was added to the paper (7198, line 12): “The use of multiple technologies on the ACME platform (i.e., broadband validation) is important, because of the large changes in ambient humidity, pressure, and temperature that the platform experiences during a flight. Mean absolute concentrations measured by a continuous analyzer are validated by comparison with flask observations. An additional level of validation is made by comparing continuous observations to each other, one analyzer having an intentional lag of 15 seconds with respect to the other one. Atmospheric fluctuations must be detected by both analyzers, one analyzer’s response to these fluctuations lagging the other analyzer’s response by 15 seconds. Any fluctuations happening simultaneously or with some other differential lags in both analyzers must be viewed as artifacts. This approach has improved objectivity of the airborne platform substantially by allowing detection and diagnostics of problems in all parts of the system: leaks in the flask sampler compressor package, drift in calibration cylinders used by the continuous analyzers, and aging of the inlet tubing.”
- 7188, 25 – The word “annual” has been deleted.
- 7188, 28 – The acronym “PBL” is defined here.
- 7189, 19 – The term “concentration” is now used consistently throughout the paper.
- 7189, 26 – “towers observations” is change to “tower observations”.

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- 7189, 26-27 – PBL, FT and SGP acronyms have already been defined. Acronyms are used.
- 7190, 2 – The second use of “As a result” is deleted.
- 7190, 14 – “for context, a annual NEE” is replace by “for context, annual NEE”.
- 7190, 15 – The acronym “NEE” is replace by “net ecosystem exchange”.
- 7191, 8 – “researchers and” was deleted, leaving “a broad set of research questions”.
- 7191, 15 – “(a.m.s.l.)” as been deleted as it appears twice and was replace by “AMSL”.
- 7192, 7 – The sentence was changes to: “These observations were the first routine measurements in the US and/or continental sites of atmospheric CO2 profiles co-located with simultaneous ground continuous CO2 flux and concentrations measurements, and were for a time the only such measurements conducted routinely over the agricultural heartland of North America.” The reference to the Langenfelds paper was deleted.
- 7192, 17 – The sentence was updated and the reviewers’ comment is now not applicable.
- 7194, 13-14 – The word “responsitivity” was change to “responsivity”.
- 7194, 20 – The word “Reduction” has been deleted and the sentence has been changed to “Diagnostics of the system (lags, flow rates, drying efficiency, temporal variability) and decomposition into vertical profiles...”.
- 7195, 2-8 – The warm-up procedure is not elaborate, it is functional and is intended to insure that both analyzers are giving good observations at launch of mission.
- 7195, 3 – sccm units have been replace by slpm units.
- 7195, 13 – “Maintenance” has been change to “maintenance”.
- 7195, 17 – “field-standards cylinders” changed to “field-standard cylinders”.

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- 7196, 12 – “O-ring sealing” changed to “O-ring seals”.
- 7196, 17 – The date given in the Figure 4 caption has been updated to “March 21, 2011”.
- 7196, 24 – “performances” has been changed to “performance”.
- 7197, 5 – “flask observations” has been changed to “flask observations”.
- 7197, 5-6 – “pair of flasks” has been changed to “pair of flask samples”.
- 7197, 7 – “measurements quality control” has been changed to “measurement quality control”.
- 7197, 18 – The word “flasks” has been replaced by “flask samples”.
- 7197, 22 – “RM0 observation” has been replaced by “RM0 observations”.
- 7198, 24-25 – “by RM0 analyzer and flask” has been deleted.
- 7199, 2 – “difficult” has been replaced by “difficulty”.
- 7199, 2-3 – “difference” has been replaced by “differences”.
- 7199, 10 – “summe” has been replaced by “summer”.
- 7199, 11 – “atmosphere” has been replaced by “atmosphere”.
- 7199, 19 – “accross” has been replaced by “across”.
- 7200, 3 – “flasks observations” has been replaced by “flask observations”.
- 7200, 11 – “the two height” has been replaced by “the two heights”.
- 7200, 21 – “concentraiton” has been replaced by “concentration”.
- Figure 1 – blue lines are hard to see and were replaced by yellow lines.
- Figure 3 – Caption was updated to include the reviewer’s comment. Caption was

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changed to: “Air flow for RM0 continuous analyzer. Note that there are feedback loops between proportional valves (not shown) and the three flow meters and pressure transducer of the buffer volume. MP is the chemical drier filled with Magnesium Perchlorate. DPT is the dew point temperature sensor.”

- Figure 5 caption, line 3 – “pressure and and flushed continuously by stream” was changed to “pressure and flushed continuously by a stream”.
- Figure 6 – Caption has been updated, “collected” has been replaced by “collected”, “shown on panel (d)” has been replaced by “shown in panel (d)”.
- Figure 7 caption, line 5 – Figure and the caption were updated to reflect reviewer’s comment.
- Figure 11 caption, line 2 – “concentrations” was changed to “concentrations”.
- Figure 11 caption, line 7 – “shadded” was replaced by “shaded”.
- Figure 12 caption, line 2 – “FT (blue)” was changed to “FT (black)”.

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Interactive comment on Atmos. Meas. Tech. Discuss., 5, 7187, 2012.

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