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Full-Column Greenhouse Gas Sampling 2012–2014 Final Campaign Report

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ARM CLIMATE RESEARCH FACILITY

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Summary

The vertical distributions of CO_2, CH_4, and other gases provide important constraints when determining terrestrial and ocean sources and sinks of carbon and other biogeochemical processes in the Earth system. The U.S. Department of Energy's (DOE) Office of Biological and Environmental Research and the National Oceanic and Atmospheric Administration's Earth System Research Laboratory to quantify the vertically resolved distribution of atmospheric carbon-cycle gases (CO_2, and CH_4) within approximately 99% of the atmospheric column at the DOE's Atmospheric Radiation Measurement Southern Great Plains (SGP) site in Oklahoma. During the 2012 to 2014 campaign period, 12 successful AirCore flights were conducted from the SGP site. In addition to providing critical data for evaluating remote sensing and earth system models, valuable lessons were learned that motivate improvements to the sampling and recovery systems and campaign logistics. With the launch of the Orbiting Carbon Observatory-2 (OCO-2) and Greenhouse gases Observing Satellite (GOSAT) satellites, we look forward to proposing additional sampling and analysis efforts at the SGP site and at other sites to characterize the vertical distribution of CO_2 and CH_4 over time and space.

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement
BER	Office of Biological and Environmental Research
DOE	U.S. Department of Energy
CH_4	methane
CO_2	carbon dioxide
ESRL	Earth System Research Laboratory
IOP	intensive observational period
NOAA	National Oceanic and Atmospheric Administration
PGS	Precision Carbon Dioxide Mixing Ratio System
OCO-2	Orbiting Carbon Observatory-2
SGP	Southern Great Plains
TCCON	Total Column Carbon Observing Network

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1.0 Background

The vertical distributions of CO_2, CH_4, and other gases provide important constraints when determining terrestrial and ocean sources and sinks of carbon and other biogeochemical processes in the Earth system. Remote sensing from ground-based and satellite-borne platforms require in situ validation. To address these measurement needs, we conducted a collaborative measurement campaign at the U.S. Department of Energy's (DOE) Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site in Oklahoma. This collaborative campaign joined the DOE Office of Biological and Environmental Research (BER) and the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) in efforts to quantify the vertically resolved distribution of atmospheric carbon-cycle gases (CO_2 and CH_4) throughout approximately 99% of the atmospheric column using AirCore sampling technology (Karion et al. 2012).

2.0 Notable Events or Highlights

During the 2012 to 2014 period, we conducted 12 successful AirCore flights from the SGP site in Oklahoma. During these 12 flights, no packages were lost, and there were no significant safety or logistical issues encountered. The data collected in this intensive observational period (IOP) represent a truly unique collection of full-column CO_2 and CH_4 atmospheric profiles that are valuable for both studies of atmospheric mixing in the upper troposphere and stratosphere and evaluation of ground and satellite remote sensing of atmospheric columns of CO_2 and CH_4. In addition, the flights at the ARM SGP site provided essential instrument development, enabling significant advances instrument design, logistics for flight and recovery, and data analysis procedures. The resulting instrument system and operations now are near a state of development in which reliable high-quality sample collection can be achieved throughout the atmospheric column.

3.0 Lessons Learned

From the flights and laboratory testing, we learned that slowing the initial descent rate of the package after release from the balloon allows better measurements to be taken during the high altitude portion of the flight. Specific lessons learned are described below:

- Sampling can be achieved with small diameter AirCore tubing, thereby allowing use of a lightweight package (<6 lb) that is exempt from Federal Aviation Administration regulations. Lightweight AirCores are now standard equipment.
- Reducing the initial decent rate is desirable because it allows the AirCore to be completely filled in the stratosphere. We now are employing a dual-balloon approach that allows a gradual decent after release from the first balloon.
- Adding a valve to the inlet of the AirCore is valuable for maintaining the integrity of the air sample in the lowest portion of the profile. An automated valve is now incorporated as a standard operating procedure.

- Guiding the descent after release from the second balloon is useful for improving speed of recovery and reducing ground hazards. Two systems for automated guidance are now being developed with support from the National Aeronautics and Space Administration.

We thank John Schatz, Craig Webb, and Pat Dowell for assistance with work at the SGP, and flight controllers at Kansas City Center and Vance Air Force Base.

4.0 Results

Over the course of the 2012 to 2014 campaign, we developed the sampling, recovery, and analysis systems, and performed 12 successful balloon launches, recoveries, and analysis operations. Figure 1 shows the schematic of the AirCore flight train used at the SGP, the balloon launch at Medicine Lodge, Kansas, and the flight trajectory from Carrier, Oklahoma. As described above, to allow gradual descent from the stratosphere, the newest configuration the AirCore now employs two smaller balloons rather than the single larger balloon shown in the figure.

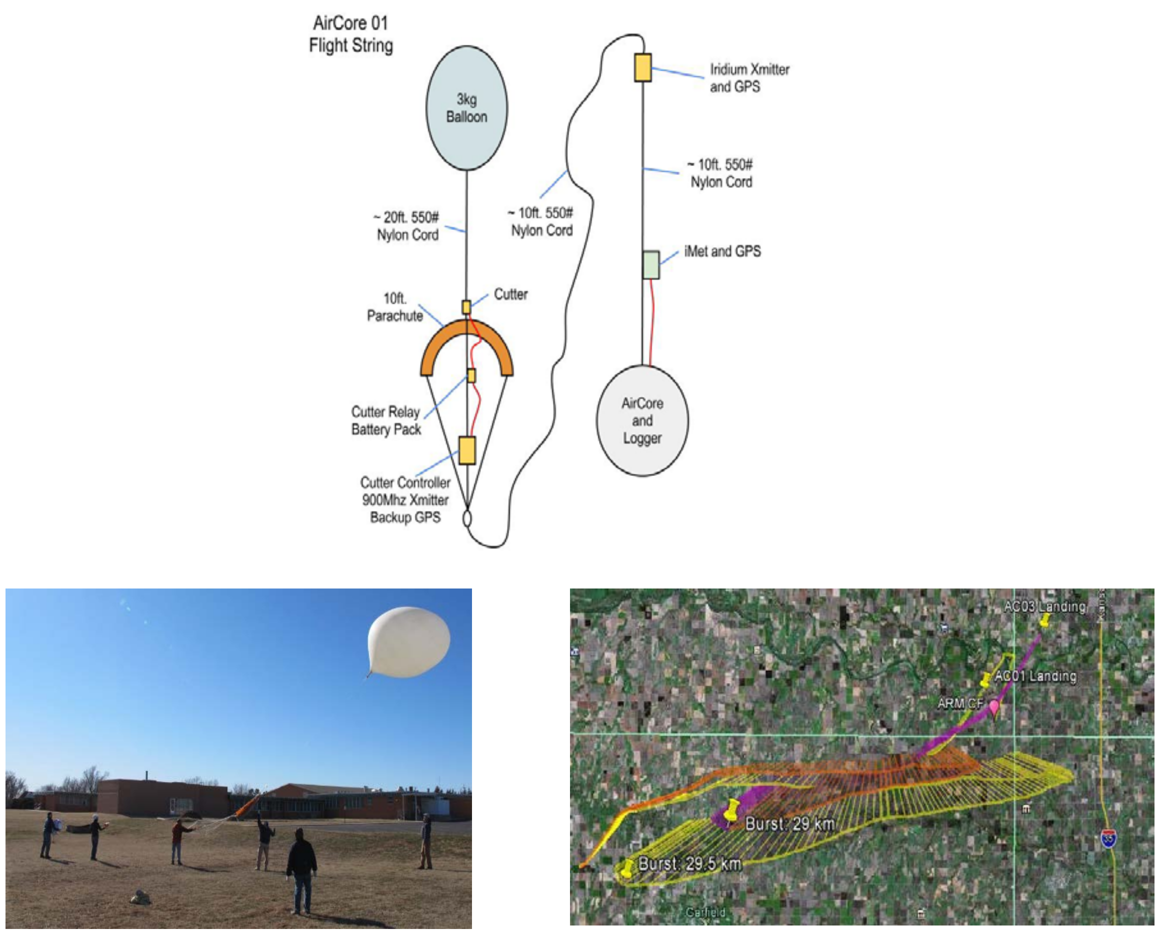

Figure 1. AirCore flight string, balloon launch, and flight trajectory. Top: The AirCore balloon string is made up of several modules including the AirCore/data logger, MET, Iridium transmitter, cutter, and parachute modules. Bottom left: Balloon launch in January 2012, from Medicine Lodge, Kansas. Bottom right: Flight trajectory in January 2012, from Carrier, Oklahoma.

Data were collected on the flight dates shown in Table 1. Data from two balloon-borne packages launched on each date provided a useful measure of reproducibility in CO_2 and CH_4 profiles obtained for the two AirCore samples. For example, Figure 2 shows example profiles of CO_2 and CH_4 obtained on a subset of flights. The general agreement of the Precision Carbon Dioxide Mixing Ratio System (PGS) data and ARM Airborne Carbon Measurements (ARM-ACME) data columns means CO_2 (and CH_4) obtained for the dual profiles are sufficient to provide valuable measurement constraints for use in evaluating remote sensed retrievals of the atmospheric columns from the Total Column Carbon Observing Network (TCCON) instrument located at the SGP and the Terrestrial Ecosystem Science, Greenhouse gases Observing Satellite (GOSAT), Orbiting Carbon Observatory-2 (OCO-2) satellite observations of CO_2 and CH_4 (for GOSAT). In addition to the comparison with TCCON and remote sensing (which is in progress), AirCore data from the SGP played a useful part in recently published observations of troposphere-stratospheric exchange rates (Ray et al. 2014).

Table 1. AirCore flight dates and comments on whether PGS and aircraft (ARM-ACME) data are available for those dates.

AirCore SGP Flight Dates (year, month, day)	PGS Data	ACME Data
20120114	Yes	Yes
20120115	Yes	Yes
20121023	Yes	No
20121024	Yes	No
20130723	No	Yes
20130724	No	Yes
20140226	Yes	Yes
20140227	Yes	Yes
20140916	Yes	No
20140917	Yes	No

As noted above, the results of this IOP demonstrate that the instrument system and operations are now near a state of development where reliable high-quality sample collection can be achieved throughout the atmospheric column on a routine basis. With the launch of the OCO-2 satellite, we consider the ARM SGP site a key site for continued evaluation of the OCO-2 column CO_2 retrievals because of the large seasonal variations in surface reflectance. We plan to propose a new IOP to gather data that will be used to provide critical tests of the OCO-2 and GOSAT data products. Directly relevant to DOE BER goals, both the AirCore profiles and column remote sensing provide data that can be used to parameterize and evaluate the Community Earth System Model being developed by DOE BER.

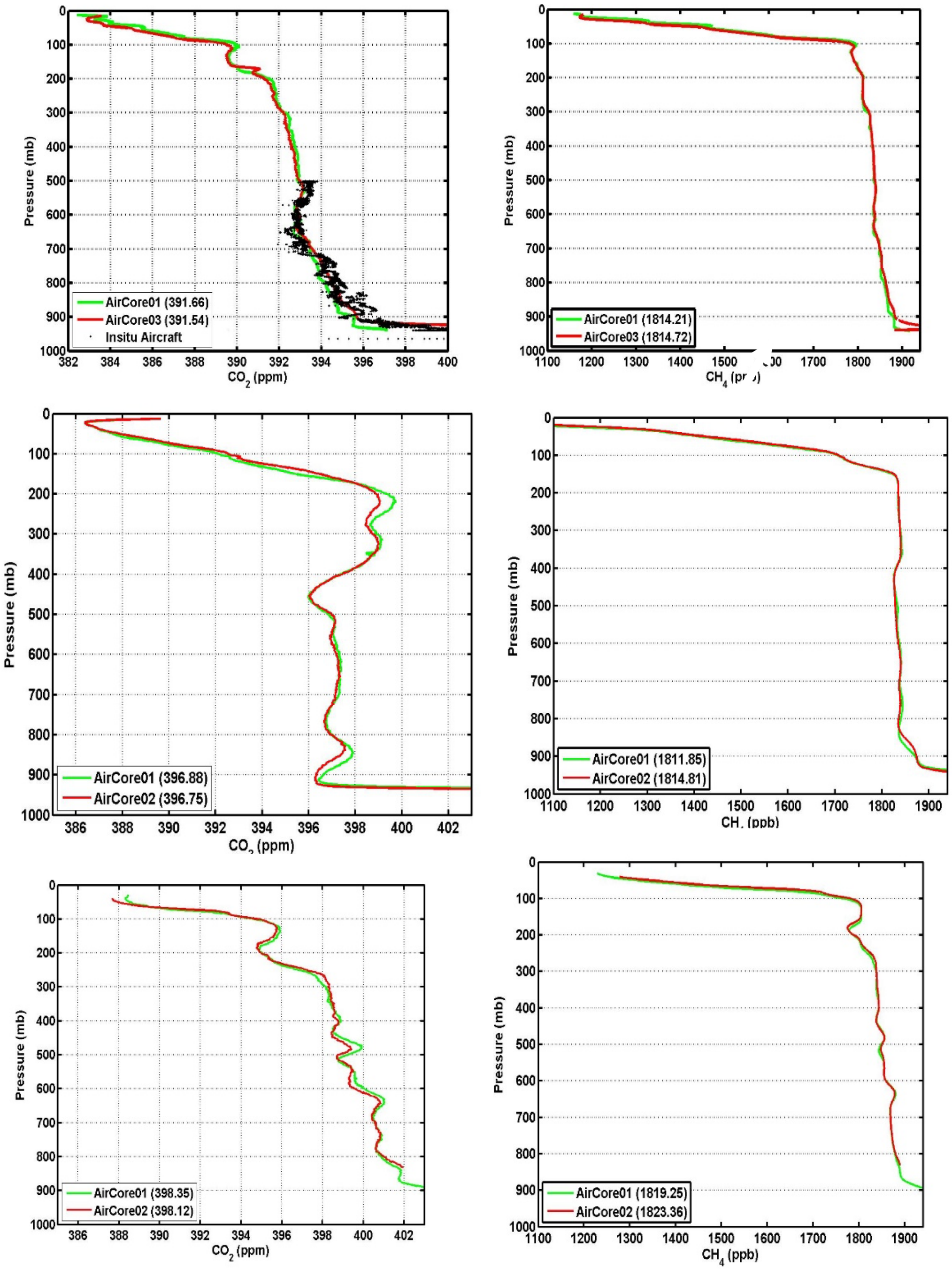

Figure 2. Measured profiles of CO_2 (left) and CH_4 (right) for two samples on each of three flight dates (top to bottom: January 15, 2012; July 23, 2013; and February 27, 2014). The close agreement of the column mean mixing ratios shown for paired samples suggests ample precision and accuracy for useful evaluation of column remote sensing. Comparison with an ARM-ACME aircraft profile of CO_2 is shown on the upper left panel.

5.0 Full-Column Greenhouse Gas Sampling 2012–2014 Publications

5.1 Journal Articles/Manuscripts

Ray, EA, FL Moore, KH Rosenlof, SM Davis, C Sweeney, P Tans, T Wang, JW Elkins, H Bönisch, A Engel, S Sugawara, T Nakazawa, and S Aoki. 2014. “Improving stratospheric transport trend analysis based on SF_6 and CO_2 measurements.” *Journal Geophysical Research: Atmospheres* 119(24):14,110-14,128, doi:10.1002/2014JD021802.

5.2 Meeting Abstracts/Presentations/Posters

Fischer, ML, C Sweeney, A Karion, J Higgs, T Newberger, S Wolter, S Biraud, R Chadwick, P Wennberg5, D Wunch, and P Tans. 2013. “Full-Column Greenhouse Gas Profiles Measured with AirCore at the ARM Southern Great Plains Site.” Poster presented at the NOAA Earth System Research Laboratory Annual Meeting, May 2013, Boulder, Colorado. Abstract available at http://www.esrl.noaa.gov/gmd/publications/annual_meetings/2013/abstracts/80-130415-B.pdf.

Fischer, ML, C Sweeney, A Karion, J Higgs, T Newberger, S Wolter, S Biraud, P Tans, and R Chadwick. 2014. “Full-column greenhouse gas profiles measured at ARM SGP.” Poster presented at the DOE Terrestrial Ecology Annual Meeting, May 2014, Potomac, Maryland. Abstract available at http://asr.science.energy.gov/meetings/stm/posters/view?id=891.

6.0 References

Karion, A, C Sweeney, P Tans, and T Newberger. 2010. “AirCore: An Innovative Atmospheric Sampling System.” *Journal of Atmospheric and Oceanic Technology* 27(11):1839-1853, doi:10.1175/2010JTECHA1448.1.

Ray, EA, FL Moore, KH Rosenlof, SM Davis, C Sweeney, P Tans, T Wang, JW Elkins, H Bönisch, A Engel, S Sugawara, T Nakazawa, and S Aoki. 2014. “Improving stratospheric transport trend analysis based on SF_6 and CO_2 measurements.” *Journal Geophysical Research: Atmospheres* 119(24):14,110-14,128, doi:10.1002/2014JD021802.

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