DOE/SC-ARM-16-019

Multi-EM27/SUN Total Carbon Column Observing Network (TCCON) Comparison at the Southern Great Plains Site Field Campaign Report

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Executive Summary

During the summer of 2015, a field campaign took place to help characterize off-the-shelf portable solar-viewing Fourier Transform Spectrometer (FTS) instruments (EM27/SUN). These instruments retrieve greenhouse gas (GHG) abundances from direct solar spectra. A focus of this campaign was to test possible dependence on different atmospheric conditions. Along with the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Climate Research Facility Southern Great Plains (SGP) site in Oklahoma, experiments were conducted in Pasadena, California; Park Falls, Wisconsin; and the Armstrong Flight Research Center (AFRC), California. These locations are home to instruments in the Total Column Carbon Observing Network (TCCON). TCCON measurements were used as standards for the portable (EM27/SUN) measurements. Comparisons between the two types of instruments are crucial in the attempt to use the portable instruments to broaden the capabilities of GHG measurements for monitoring, reporting, and verification of carbon in the atmosphere.

This campaign was aimed at testing the response of the portable FTS to different atmospheric conditions both local and regional. Measurements made at ARM SGP provided data in an agricultural environment with a relatively clean atmosphere with respect to pollution. Due to the homogeneity of the region surrounding Lamont, Oklahoma, portable FTS measurements were less effected by large changes in column GHG abundances from air mass movement between regions. These conditions aided in characterizing potential artificial solar zenith angle dependence of the retrievals. Data collected under atmospheric conditions at ARM SGP also provide for the analysis of cloud interference on solar spectra. In situ measurements were also made using a Picarro isotopic methane analyzer to determine surface-level in situ GHG concentrations and possible influences due to local agriculture and nearby towns.

Data collected in this campaign have been presented via a poster at the American Geophysical Union Fall Meeting in 2015 and is included in a paper that is in preparation to be submitted to *Atmospheric Measurement Techniques* in 2016.

Acronyms and Abbreviations

AFRC	Armstrong Flight Research Center
AGU	American Geophysical Union
ARM	Atmospheric Radiation Measurement Climate Research Facility
Caltech	California Institute of Technology
CMS	Carbon Monitoring System
CRDS	Cavity Ring Down Spectrometer
DMF	dry air mole fraction
EM27/SUN	a Bruker Optics™ portable solar-viewing spectrometer
FTS	Fourier Transform Spectrometer
GHG	greenhouse gas
GOSAT	Greenhouse gases Observing SATellite
ILS	instrument line shape
IR	infrared
IRWG	Infrared Working Group, part of the NDACC
LANL	Los Alamos National Laboratory
LDRD	Laboratory Directed Research and Development
ME	modulation efficiency
MOPD	maximum optical path difference
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NTP	Network Time Protocol
OCO-2	Orbiting Carbon Observatory-2
SGP	Southern Great Plains
TCCON	Total Carbon Column Observing Network
VMR	volume mixing ratio

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1.0 Background

In 2013 Bruker Optics™ began to market a new type of solar-viewing spectrometer named the EM27/SUN. These spectrometers measure near-infrared (IR) solar spectra. From these spectra, column abundances of GHGs such as CO_2 and CH_4 are retrieved. This concept is well established and has been used by the TCCON (Wunch et al. 2011) for over 10 years. An accurate knowledge of GHG column volume mixing ratios (VMRs) is necessary to help in understanding global climate change. In this campaign we sought to understand the limits of accuracy and precision of these instruments. To do so, we compared measurements with the TCCON measurements at the ARM SGP site.

The ARM SGP research site was one of four different research sites in the U.S. Other sites are located in Pasadena, California, at AFRC, California, and in Park Falls, Wisconsin. Each of these locations also has a TCCON site. We sought to answer several questions, as follows. 1) Do the atmospheric conditions affect biases between EM27/SUN instruments and TCCON? 2) Do the EM27/SUN instrument measurements drift amongst themselves with time? 3) What are the EM27/SUN-to-TCCON biases? 4) Are there any small (<0.5 ppm and <5 ppb) differences in column averaged dry air CO_2 and CH_4 (X_{CO2} and X_{CH4}) among TCCON sites? This campaign was the first to help make progress towards answering these questions.

In this report we focus on the part of the campaign that took place at the SGP ARM site near Lamont, Oklahoma, in August-September 2015. Details about comparisons at other locations and other times will be included in future publications. This study is significant because it is the first that involves comparing multiple EM27/SUN spectrometers at multiple TCCON measurement sites. It also is part of the first attempt to determine biases among different TCCON sites from ground measurements. We anticipate that lessons learned from this campaign may be applied across the global TCCON network.

The intercomparison at the SGP ARM site was August 31-September 4 2015. The basic daily task was to arrive at sunrise and set up measurements by two separate EM27/SUN instruments until sunset. In addition to solar spectra, we also collected ancillary meteorological measurements. For half a day we characterized the instrument line shape (ILS) of the EM27/SUN instruments to note if they were stable after all the travel they had been subjected to. Surface in situ CO_2, and CH_4 VMRs were also measured by a Picarro G2201-i Cavity Ring Down Spectrometer (CRDS) analyzer.

Besides being a collaborative effort with the ARM Facility, this work also involved participants from Los Alamos National Laboratory (LANL) and the California Institute of Technology (Caltech), with one EM27/SUN owned by each of these institutions. Harrison Parker (LANL) oversaw the EM27/SUN measurements at the SGP ARM site. Jacob Hedelius (Caltech) also made onsite measurements. Both ran EM27/SUN retrievals using GGG2014 to obtain dry air mole fractions (DMFs) of CO_2 and CH_4 from the solar IR spectra (Wunch et al. 2015). Manvendra Dubey (LANL) and Paul Wennberg (Caltech) directed the research and secured funding. Debra Wunch and Coleen Roehl (Caltech) performed TCCON retrievals. Camille Viatte (Caltech) assisted in preparing the EM27/SUN spectrometers for measurements.

This research was funded in part by the National Aeronautics and Space Administration (NASA) Carbon Monitoring System (CMS) program, the LANL Laboratory Directed Research and Development (LDRD) program, the NASA Carbon Cycle Science Program, the NASA Jet Propulsion Laboratory, the W. M.

Keck Institute for Space Studies, and a Caltech Chemistry and Chemical Engineering Division Fellowship funded by the Dow Chemical Company.

2.0 Notable Events or Highlights

Campaign days at the SGP were similar. Most days were warm, with moderate wind speeds. The sky was clear, though dotted with popcorn clouds approximately 40% of the time. Thick clouds did affect the measurements, though most data can easily be screened during cloudy events. The EM27/SUN owned by LANL had a modulation efficiency (ME) at maximum optical path difference (MOPD) of 0.997 and the EM27/SUN owned by Caltech had an ME at MOPD of 0.983 at the site.

During the first two days the Picarro measured significant cyclic variations in H_2O. We attributed this to the long coil of tubing inside the building housing the Picarro that lead outside. These cyclic variations stopped when the excess coil was placed outside instead. The variations were attributed to the air conditioning of the building turning on and off.

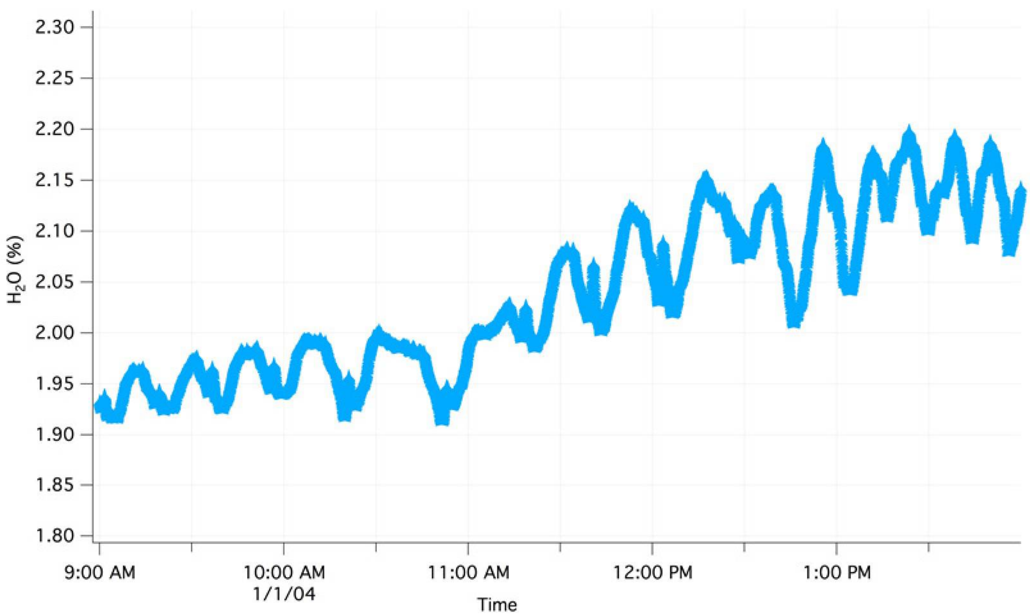


Figure 1. H_2O measurements from in situ Picarro instrument showing oscillations attributed to air conditioning cycles within building. Fixed by placing working loops of inlet tubing outside.

3.0 Lessons Learned

Retrievals of X_{gas} require accurate recording of time (better than 1 s) for precise measurements. Typically this is not a problem for measurements because the instruments are synchronized to the computers daily and the computers are synchronized through the Microsoft Windows network time protocol (NTP) client daily when connected to the Internet. However, onsite computers were not connected to the Internet and not regularly synchronized. This could be the cause of timing error differences we see between the two instruments (Fig. 2).

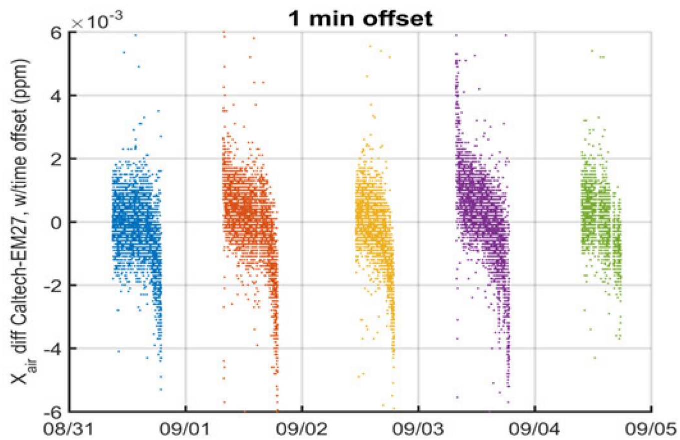


Figure 2. Differences in X_{air} (a diagnostic) between the two spectrometers. The rotated sigmoidal shapes indicate a timing error. We implemented a 1-minute offset to reduce the magnitude of the shape.

We also noted a drift in X_{CO2} measured by the two spectrometers throughout the duration of the campaign (Fig. 3). Much of this drift occurred while at the SGP site. We anticipate using measurements from the onsite TCCON instrument to help us determine which EM27/SUN instrument was predominately drifting. This drift may be related to timing errors.

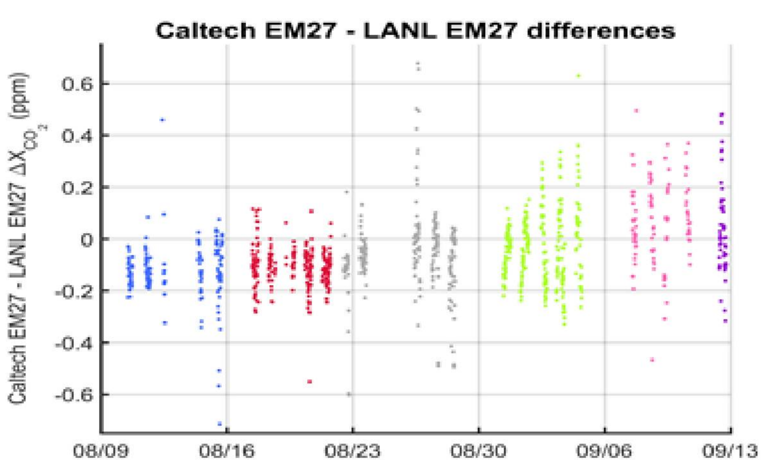


Figure 3. Differences between EM27/SUN measurements at different locations. Green represents measurements at the SGP site in 2015.

4.0 Results

Data for this campaign was collected from four separate TCCON sites and compared with two EM27/SUN instruments to determine the biases between the TCCON retrievals and the EM27/SUN retrievals, as well as bias between retrievals from the two EM27/SUN instruments. The high-resolution FTS instrument used by TCCON is tied to the WMO scale through extensive airborne measurements (D. Wunch et al. 2010). For these reasons, the TCCON measurements are used as a "truth" reference. This is helpful when attempting to characterize new portable FTS instruments. Differences between the high-resolution FTS and the EM27/SUN measurements are shown in Figure 4. Differences in X_{ch4} change from 6 ppb to 20 ppb depending on the day and time of day. The average offset for X_{ch4} is 11 ppb and 12 ppb for the LANL portable FTS and the Caltech portable FTS respectively. Offsets from TCCON measurements are thought to be due in part to resolution differences. We hypothesize that intraday change of the X_{ch4} differences is due to in part to changing atmospheric conditions. Water absorption lines are close to methane absorption lines, so changing water abundance may cause apparent changes in methane retrievals. Cloud interactions may also affect measurements when not properly filtered. X_{CO2} diurnal patterns are minimal and attributed to daily differences in the atmosphere and to air mass dependency issues.

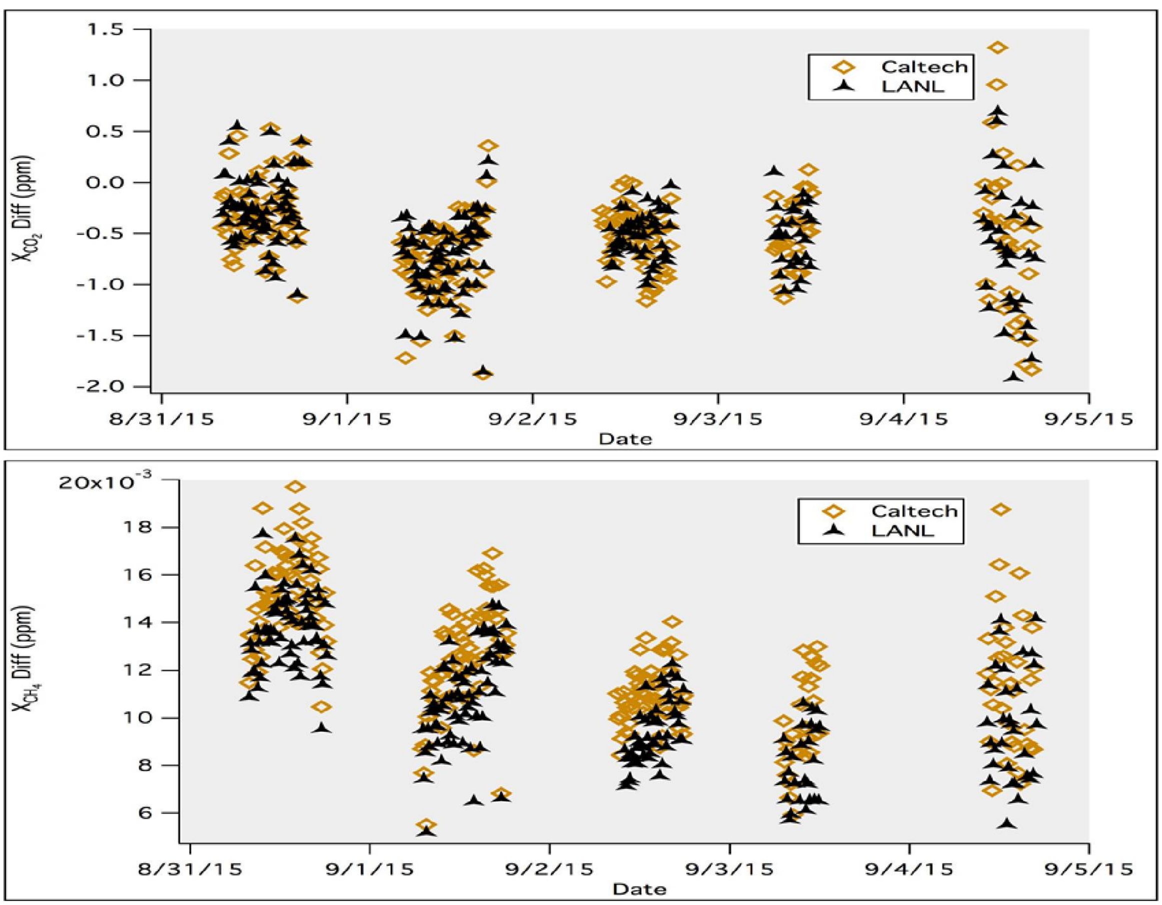


Figure 4. Time series of ARM SGP differences of TCCON and EM27/SUN measurements for X_{CO2} (top) and X_{CH4} (bottom).

Average measurement differences between the two EM27/SUN instruments across the entire campaign were 1.5 ppb and 0.05 ppm for X_{ch4} and X_{CO2} respectively (shown in Figure 5). The averages for ARM SGP-specific measurements were 1.5 ppb and 0.03 ppm for X_{ch4} and X_{CO2} respectively. Understanding the drifts between the portable instruments is crucial to guaranteeing high-quality data and allowing for use of the instrument for independent, reliable column measurements without having a high-resolution spectrometer nearby.

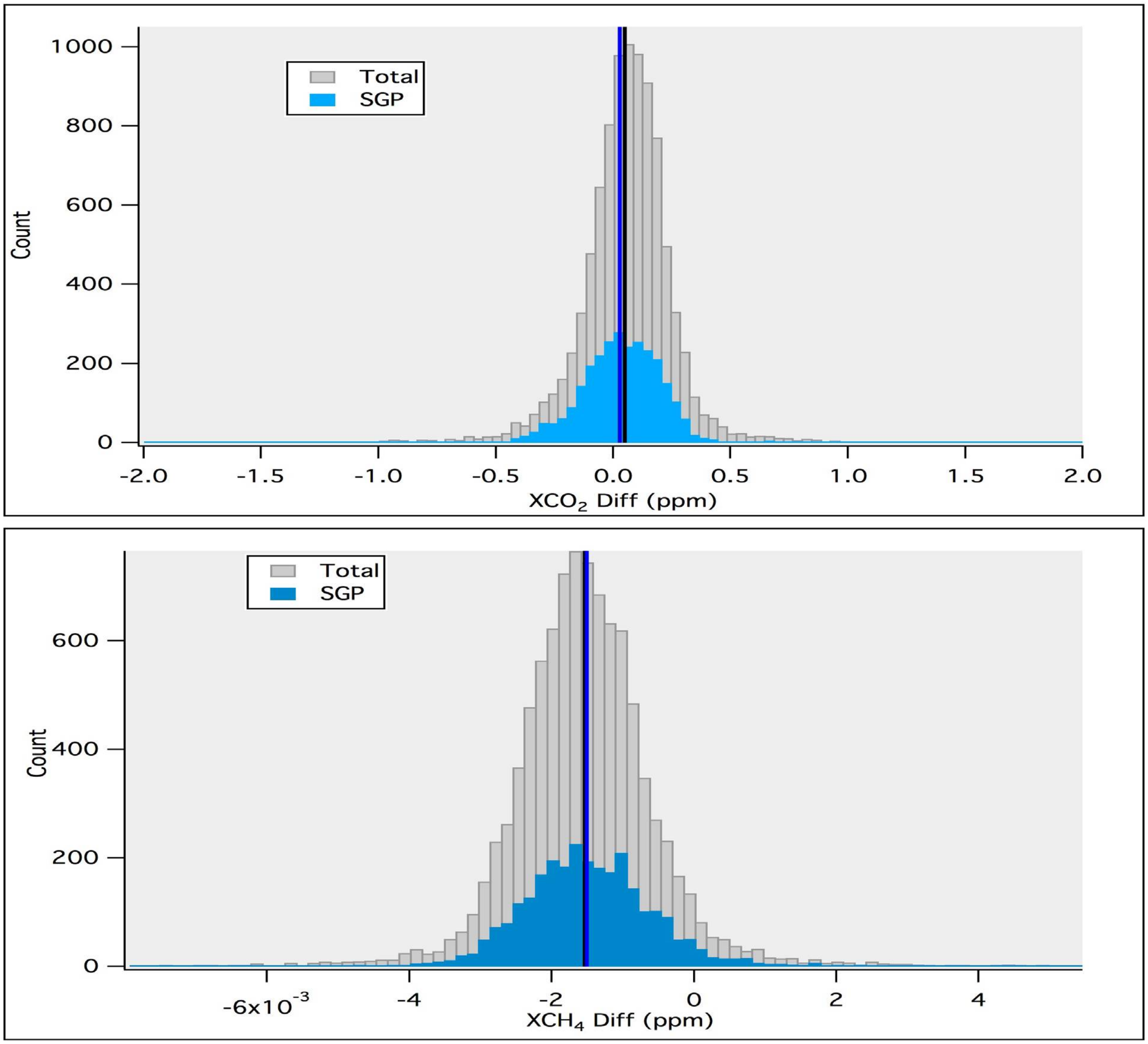
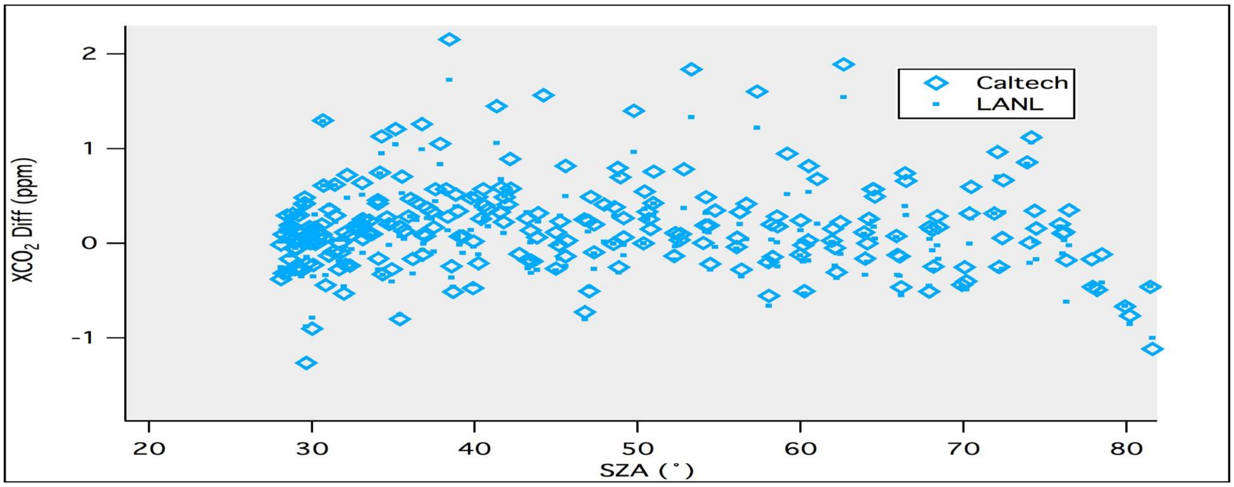


Figure 5. Histograms of the differences between LANL and Caltech EM27/SUN instruments at ARM SGP for X_{CO2} (top) and X_{CH4} (bottom).

Spectra gathered by all three instruments are processed using GGG2014, which includes the GFIT retrieval algorithm (Wunch et al. 2015). GGG2014 uses an empirical correction for measurements of larger air masses (higher solar zenith angles). The correction is applied based on the TCCON data, but this correction may not extend to the data from the EM27/SUN. Since the EM27/SUN has a lower resolution, it is expected to act differently when dealing with larger air masses. The magnitude of the effect of viewing larger air masses by the portable FTS is shown in Figure 6. This analysis shows that the influence of viewing larger air masses may cause differences by 0.1% at most at ARM SGP. The lack of influence suggests a similar air mass dependence as the TCCON.



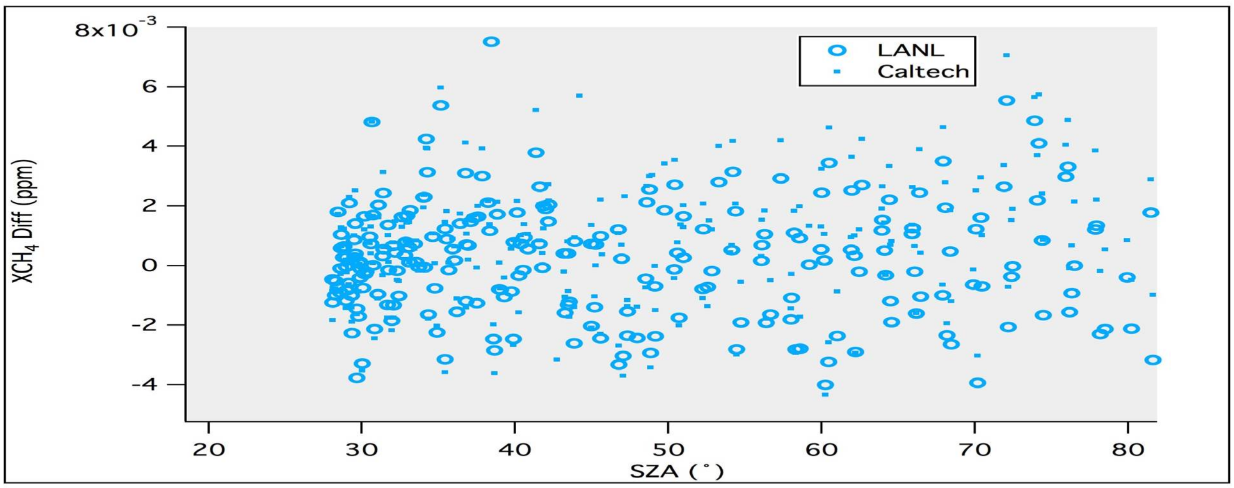


Figure 6. Plots of differences between EM27/SUN data and midday TCCON data to find possible solar zenith angle dependences.

5.0 EM27/SUN to TCCON Multisite Comparisons Publications

5.1 Journal Articles/Manuscripts

Results from this campaign are being prepared for peer-reviewed publication.

Parker, H, J Hedelius, C Viatte, J Podolske, C Roehl, D Wunch, P Hillyard, LT Iraci, P Wennberg, MK Dubey, and F Hase. "Critical comparison of two portable FTS instruments using TCCON as standard. "In preparation for submission to Atmospheric Measurement Technologies in 2016.

5.2 Meeting Abstracts/Presentations/Posters

Results from this campaign were presented at the American Geophysical Union fall meeting, 2015. We anticipate that results from this campaign will also be presented at the TCCON/Network for the Detection of Atmospheric Composition Change (NDACC)-Infrared Working Group (IRWG) meeting as well.

Parker, H, J Hedelius, C Viatte, J Podolske, C Roehl, D Wunch, P Hillyard, LT Iraci, P Wennberg, MK Dubey, F Hase, J Chen, J Franklin, T Jones, and S Wofsy. 2015. “Compact solar spectrometer Column CO2 and CH4 observations: Performance evaluation at multiple North American TCCON sites.” Poster presented at American Geophysical Union Fall Meeting; San Francisco, CA; December 14-18, 2015.

6.0 References

Wunch, D, GC Toon, J-FL Blavier, RA Washenfelder, J Notholt, BJ Connor, DWT Griffith, V Sherlock, and PO Wennberg. 2011. "The Total Carbon Column Observing Network." *Philosphical Transactions of the Royal Society A* 369(1943): 2087–2112, doi:10.1098/rsta.2010.0240.

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Wunch, D, GC Toon, PO Wennberg, SC Wofsy, BB Stephen, ML Fischer, and O Uchino. “Calibration of the Total Carbon Column Observing Network using aircraft profile data.” *Atmospheric Measurement Techniques* 3: 1351-1362, doi:10.5194/amt-3-1351-2010.

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