ACT-America: L1 Raw, Uncalibrated In-Situ CO2, CO, and CH4 Mole Fractions from Towers

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Documentation Revision Date: 2020-10-30

Dataset Version: 1

Summary

This dataset provides Level 1 (L1) in situ atmospheric carbon dioxide (CO2), carbon monoxide (CO), and methane (CH4) concentrations as measured on a network of instrumented communications towers across the central and eastern USA operated by the Atmospheric Carbon and Transport-America (ACT-America) project. There were 11 towers instrumented with cavity ring-down spectrometers (CRDS; Picarro Inc.) with measurements beginning in January 2015 and continuing to October 2019. The measurement period varied by tower site. The Picarro analyzers continuously measured total CH4, isotopic ratio of CH4, CO2, CO, and other greenhouse gas concentrations. Not all species were measured at all sites. Complete tower location, elevation, instrument height, and date/time information are also provided. Determination of greenhouse gas fluxes and uncertainty bounds is essential for the evaluation of the effectiveness of mitigation strategies. These L1 data are raw instrument outputs from the Picarro instruments. A Level 2 (L2) product derived from this L1 data is available and generally would be the preferred data for most use cases.

ACT-America's overall mission spanned five years and included field campaigns covering all four seasons over central and eastern regions of the United States. ACT-America's objectives were to study the transport and fluxes of atmospheric CO_2 and CH_4. Two instrumented aircraft platforms, the NASA Langley Beechcraft B-200 King Air and the NASA Wallops Flight Facility's C-130 Hercules, were used to collect high-quality in situ measurements across a variety of continental surfaces and atmospheric conditions. At times they flew directly under Orbiting Carbon Observatory-2 (OCO-2) overpasses to evaluate the ability of OCO-2 to observe high-resolution atmospheric CO_2 variations. The C-130 aircraft was also equipped with active remote sensing instruments for planetary boundary layer height detection and column greenhouse gas measurements.

This dataset contains 28 files in netCDF (*.nc) format.

Figure 1. The communication tower at the Wessington, South Dakota site. This site was instrumented from January of 2017 to September of 2019.

Citation

Miles, N.L., S.J. Richardson, D.K. Martins, K.J. Davis, and B.J. Haupt. 2020. ACT-America: L1 Raw, Uncalibrated In-Situ CO2, CO, and CH4 Mole Fractions from Towers. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1798

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1. Dataset Overview

This dataset provides Level 1 (L1) in-situ atmospheric carbon dioxide (CO_2), carbon monoxide (CO), and methane (CH_4) concentrations as measured on a network of instrumented communications towers across the central and eastern USA operated by the Atmospheric Carbon and Transport-America (ACT-America) project. There were 11 towers instrumented with cavity ring-down spectrometers (CRDS; Picarro Inc.) with measurements beginning in January 2015 and continuing to October 2019. The measurement period varied by tower site. The Picarro analyzers continuously measured total CH_4, isotopic ratio of CH_4, CO_2, CO, and other greenhouse gas concentrations. Not all species were measured at all sites. Complete tower location, elevation, instrument height, and date/time information are also provided. Determination of greenhouse gas fluxes and uncertainty bounds is essential for the evaluation of the effectiveness of mitigation strategies. These L1 data are raw instrument outputs from the Picarro instruments. A Level 2 (L2) product derived from this L1 data is available and generally would be the preferred data for most use cases.

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Project: Atmospheric Carbon and Transport - America

The ACT-America, or Atmospheric Carbon and Transport - America, project was a NASA Earth Venture Suborbital-2 mission to study the transport and fluxes of atmospheric carbon dioxide and methane across three regions in the eastern United States. ACT-America conducted five flight campaigns spanning all four seasons throughout 2016—2019 and measured how weather systems transported greenhouse gases. Ground-based measurements were also collected. The objective of the study was to enable more accurate and precise estimates of the sources and sinks of greenhouse gases, as better estimates are needed for climate management and for prediction of future climate. Three primary sources of uncertainty (i.e., transport error, prior flux uncertainty, and limited data density) were addressed to improve the inference of carbon dioxide and methane sources and sinks.

Related Datasets

Digangi, J.P., Y. Choi, J.B. Nowak, and H.S. Halliday. 2017. ACT-America: L2 In Situ Atmospheric CO2, CO, CH4, and O3 Concentrations, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1556

Miles, N.L., S.J. Richardson, D.K. Martins, K.J. Davis, T. Lauvaux, B.J. Haupt, and S.K. Miller. 2018. ACT-America: L2 In Situ CO2, CO, and CH4 Concentrations from Towers, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1568

Acknowledgments

The Monroe, Magee, Millerville, and Panama City tower sites were supported by NASA grants NNX14AJ17G for 2015—2016, and NNX14AJ17G and NNX15AG76G for 2017. The Grenada tower site was supported by NASA grant NNX14AJ17G for 2015—2016. For 2017, it was funded by NASA grants NNX14AJ17G and NNX15AG76G and the NOAA grant RA-133R-18-SE-0020. The Greenfield, Mooresville, and Crawfordsville tower sites were supported by the National Institute of Standards and Technology grant 70NANB10H245. The Mildred tower site was supported by the DOE National Energy Technology Laboratory grant DE-FOA-0000894 for 2015—2016 and by NASA grant NNX15AG76G for 2017.

2. Data Characteristics

Spatial Coverage: Tower locations over eastern and central US

Spatial Resolution: Point measurements

Temporal Coverage: 2015-01-01 to 2019-12-31

Temporal Resolution: Approximately 2-3 seconds

Study Area: Latitude and longitude are given in decimal degrees.

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
Eastern and Central United States	-98.587972	-76.4188	44.05015	30.1951

Table 1. Site Details and tower decommissioning dates.

Site Name	Site Abbreviation	Latitude	Longitude	Installation	Decommissioning
Millerville, Alabama	AL-01	33.1759	-85.8911	2015-03-19	2018-10-17
Panama-City, Florida	FL-01	30.1951	-85.8336	2015-03-20	2019-12-11
Monroe, Louisiana	LA-01	32.469	-92.2829	2015-03-22	2018-10-15
Magee, MS	MS-01	31.8869	-89.7276	2015-03-21	2017-10-15
Grenada, MS	MS-02	33.7525	-89.8539	2015-03-23	2019-10-03

Danville, Virginia	DVV	36.705806	-79.436861	2016-07-13	2018-12-04
Wessington, South Dakota	WSD	44.05015	-98.587972	2017-02-04	2019-09-20
Marcellus South - Mildred, PA	MRC	41.4662	-76.4188	2015-05-07	
Mooresville, IN	IN-01	39.5805	-86.4207	2010-09-22	
Greenfield, IN	IN-09	39.8627	-85.7448	2012-03-30	
Crawfordsville, IN	IN-14	39.9971	-86.7396	2017-04-26	

Data File Information

This dataset contains 28 data files in netCDF (*.nc) format following CF Conventions (v1.6). There can be multiple files per site but not all sites have data for all years.

File Naming Convention

Files are named according to the format **<project>-<instrument>_<platform>-<level>_<station>_<instrument-id>_<startdate>_<enddate>.nc** (e.g., ACTAMERICA-PICARRO_Tower-L1_Danville_CADS05_20180125_20181203.nc), where:

<project> = ACTAMERICA

<instrument> = PICARRO

<platform> = Tower

<level> = L1

<station> = tower site names (Crawfordsville, Danville, Greenfield, Grenada, Magee, Mildred, Monroe, Mooresville, Millerville, Panama-City, Wessington)

<instrument-id> = instrument ID

<startdate> = start date in UTC, in YYYYMMDD format

<enddate> = end date in UTC, YYYYMMDD format

Data File Details

Table 1. Variable names, units, and descriptions. Not all variables are available in all files.

FRAC_DAYS_SINCE_JAN1 solenoid_valves OutletValve

Variable Name	Units	Description
Station Information		
site_name		Site name (Stations: Crawfordsville, Danville, Greenfield, Grenada, Magee, Mildred, Monroe, Mooresville, Millerville, Panama-City, Wessington)
latitude	decimal degrees north	Site latitude
longitude	decimal degrees east	Site longitude
altitude	meter	Elevation of tower base above sea level
sampling_height	meter	Sampling height above ground level
Time Series Variables		
time	hours since 2015-01-01 00:00:00.0 UTC	
fractional days	fractional days	Fractional days since January 1 of the current year (add 1 to get day-of-year)
FRAC_HRS_SINCE_JAN1 *	hours	Fractional hours since January 1 (add 1x24 to get a day of the year in hours)
JULIAN_DAYS *	days	Julian days
EPOCH_TIME *	seconds	Number of seconds elasped since UNIX epoch
ALARM_STATUS		System alarm: 0=good, 1=bad
CavityPressure	Torr	Pressure in the cavity of the instrument
CavityTemp	degrees Celsius	Temperature in the cavity of instrument
WarmBoxTemp *	degrees Celsius	Temperature of the instrument warm box
DasTemp	degrees Celsius	Room temperature
MPVPosition *		Rotary valve flag
solenoid_valves		0=air sample, 8=cal 1, 16=cal 2; inlets used for sampling different gas sources
InletValve		The opening of inlet valve of cavity which is always kept open at a fixed position

OutletValve		The opening of outlet valve of cavity which varies between fully closed and value fully opened to ensure stability of cavity pressure
species		An indicator function of gas species update; 1 if CO2, 2 if CH4, 3 if H2O, and 4 if CO
CH4	ppmv	CH4 mixing ratio without vapor correction in parts per million by volume
CH4_dry	ppmv	Dry CH4 mixing ratio in parts per million by volume
CO	ppmv	Dry CO mixing ratio in parts per million by volume
CO2	ppmv	CO2 mixing ratio without vapor correction in parts per million by volume
CO2_dry	ppmv	Dry CO2 mixing ratio in parts per million by volume
H2O	percent	Water vapor mixing ratio of dried sample in parts per hundred by volume; useful only for diagnostic purposes
h2o_pct	percent	Percent concentration of water vapor, not recommended for use
h2o_reported	percent	Reported concentration of concentration of water vapor, used for vapor correction, not recommended for use
b_h2o_pct	percent	Absorption line of H2O that are adjacent to the line of CO, not recommended for use
Delta_iCH4_Raw *	per mil	Raw (not averaged) isotopic ratio of CH4
HP_12CH4 *	ppmv	High precision 12CH4
HP_Delta_iCH4_2min *	per mil	2 minute mean of isotopic ratio of CH4 (high precision)
HP_Delta_iCH4_30s *	per mil	30 second mean of isotopic ratio of CH4 (high precision)
HP_Delta_iCH4_5min *	per mil	5 minute mean of isotopic ratio of CH4 (high precision)
HP_Delta_iCH4_Raw *	per mil	Raw (not averaged) isotopic ratio of CH4 (high precision)
HR_12CH4*	ppmv	High range 12CH4
HR_Delta_iCH4_2min *	per mil	2 minute mean of isotopic ratio of CH4 (high range)
HR_Delta_iCH4_30s *	per mil	30 second mean of isotopic ratio of CH4 (high range)
HR_Delta_iCH4_5min *	per mil	5 minute mean of isotopic ratio of CH4 (high range)
HR_Delta_iCH4_Raw *	per mil	Raw (not averaged) isotopic ratio of CH4 (high range)
ChemDetect *		Detection of possible contaminants

* Indicates that a variable is available for the Mildred site only.

Companion Files

Picarro instrument specifications are found in the files *datasheet-g2301-crds-analyzer-co2-ch4-h2o-air-oct15.pdf* and *G2301-m+Manual+rev+2-11-11.pdf*. Individual site/tank information is provided in the file *Tank_log_raw_data.xlsx*.

Data Center Processing

The ORNL DAAC transformed and combined ~15,000 files from the originally provided DAT format to 28 files in CF-compatible netCDF4 format to make them easier to understand and to use.

3. Application and Derivation

ACT-America, or Atmospheric Carbon and Transport - America, conducted five airborne campaigns across three regions in the eastern United States to study the transport and fluxes of atmospheric carbon. The eastern half of the United States is a region that includes a highly productive biosphere, vigorous agricultural activity, extensive gas and oil extraction and consumption, dynamic, seasonally varying weather patterns and the most extensive carbon cycle and meteorological observing networks on Earth, serves as an ideal setting for the mission.

Each 6-week campaign accurately and precisely quantified anomalies in atmospheric carbon, also known as carbon flux. Accurate carbon flux data is necessary to address all terrestrial carbon cycle science questions. ACT-America addressed the three primary sources of uncertainty in atmospheric inversions—transport error, prior flux uncertainty, and limited data density.

ACT-America advances society's ability to predict and manage future climate change by enabling policy-relevant quantification of the carbon cycle. Sources and sinks of atmospheric carbon dioxide (CO_2) and methane (CH_4) are poorly known at regional to continental scales. ACT-America enables and demonstrates a new generation of atmospheric inversion systems for quantifying CO_2 and CH4 sources and sinks.

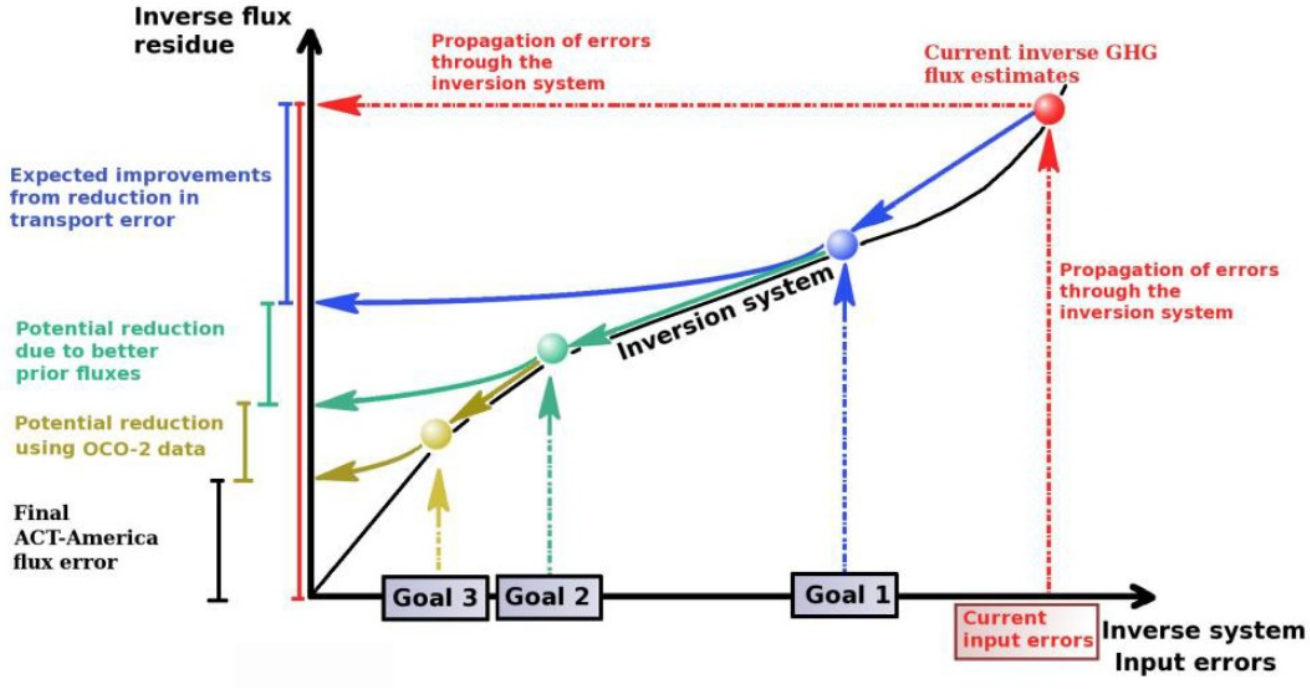

Figure 3. A schematic showing ACT-America mission goals.

ACT-America Goals

1. To quantify and reduce atmospheric transport uncertainties.
2. To improve regional-scale, seasonal prior estimates of CO_2 and CH_4 fluxes.
3. To evaluate the sensitivity of Orbiting Carbon Observatory (OCO-2) column measurements to regional variability in tropospheric CO_2.

ACT-America achieved these goals by deploying airborne and ground-based platforms to obtain data that were combined with data from existing measurement networks and integrated with an ensemble of atmospheric inversion systems. Aircraft instrumented with remote and in-situ sensors observed how mid-latitude weather systems interact with CO_2 and CH_4 sources and sinks to create atmospheric CO_2/CH_4 distributions. A model ensemble consisting of a mesoscale atmospheric transport model with multiple physics and resolutions options nested within global inversion models and surface CO_2/CH_4 flux ensembles was used to predict atmospheric CO_2 and CH_4 distributions.

Beyond the conclusion of the mission, the application of knowledge gained from this mission will improve diagnoses of the carbon cycle across the globe for decades.

4. Quality Assessment

Calibration: Prior to deployment, the instruments were calibrated in the laboratory using four NOAA-calibrated tanks. A field calibration tank was sampled daily and used to apply a zero-offset correction. Round robin tests using 3-4 NOAA-calibrated tanks were conducted every 1-2 years. NOAA flask measurements were used for comparison at the Mildred, Greenfield, and Mooresville sites. Individual site/tank information is provided in the file *Tank_log_raw_data.xlsx* found in the companion file for this dataset.

Uncertainty: Based on the flask to in-situ comparisons and round-robin testing presented in Richardson et al. (2017), the estimated compatibility of these measurements is approximately 0.18 ppm CO_2 and 0.6 ppb CH_4. Instrument precision specifications are available in the ACT-America proposal and replicated below (Fig. 3).

Instrument	Platform	Technique	TRL	Species/ Parameter	Instrument Precision (Averaging Time)	STM Precision Requirement [over 20 km (~130 sec) unless otherwise noted]
MFLL	C-130H	LAS[1]	8	CO_2 Column Density[4]	≤0.08% (10 sec) ≤0.25% (1 sec)	0.1% 1% (0.2 km)
		Pseudorandom Number Altimetry		Range to ground	< 1m (0.1 sec)	5 m (0.2 km)
HSRL	C-130H	Pulsed Lidar	9	ABL Height[5]	≤ 100 m (10 sec)	100 m
Picarro G2401-m	C-130H, B200	CRDS[2]	9	CO_2	≤ 0.15 ppm (5 sec)	1 ppm
				CH_4	≤ 1 ppb (5 sec)	4 ppb
				CO	≤ 30 ppb (5 sec)	15 ppb
				H_2O	≤ 0.12 g/kg (5 sec)	0.5 g/kg
2B Technologies Model 205	C-130H, B200	Laser Spectrometer	9	O_3	1 ppb (10 sec)	8 ppb
Picarro G2301	Tower	CRDS[2]	9	CO_2	≤ 0.07 ppm (5 sec)	1 ppm hourly
				CH_4	≤ 0.5 ppb (5 sec)	4 ppb hourly
Flasks	C-130H, B200	GC/ MS[3]	9	CO_2, CH_4, CO, $^{14}CO_2$, COS	0.2 ppm CO_2;1 ppb CH_4; 2 per mil $^{14}CO_2$;2 ppt COS; (all 10 sec)	1 ppm CO_2; 4 ppb hourly CH_4; 2 per mil $^{14}CO_2$; 10 ppt COS
Environmental Parameters Suite	C-130H	INS[3]	9	Wind Speed and Direction	1 m/s; +/- 5 degrees (0.1 sec)	1 m/s; 5 degrees
	C-130H, B200	Various		Pressure	0.25 mbar (0.015 sec)	0.5 mbar
				Temperature	0.2 degrees Celsius (0.15 sec)	0.5 degrees Celsius

[1]LAS = Laser Absorption Spectroscopy; [2]CRDS = Cavity Ring-Down Spectroscopy; [3]GC/MC = Gas Chromatography/Mass Spectroscopy; [3]INS = Inertial Navigation System; Note that location, altitude, air speed, and aircraft pitch, roll, and yaw, are also provided and recorded by onboard aircraft systems. [4]MFLL also provides surface reflectance variability. [5]HSRL also

Figure 3. Instrument precision table as provided in the ACT-America proposal.

5. Data Acquisition, Materials, and Methods

ACT-America Overview

ACT-America deployed the NASA C-130 and B-200 aircraft to measure atmospheric CO_2 and CH_4 in the atmospheric boundary layer (ABL) and free troposphere (FT). In all five seasonal campaigns, a total of 121 days of research flights, more than 1,140 hours of observations, 570 level legs, and 1,363 vertical profiles were conducted. Flights concentrated observations on three study domains: Northeast, South-central, and Midwest. These flights were dedicated in a roughly 3:3:1 ratio among fair weather, stormy weather, and OCO-2 underpass flight patterns.

For fair and stormy weather flights, the C-130 flew at 3-8 km above ground, collecting in-situ measurements in the lower FT, remotely sensed, column-averaged CO_2 measurements focused on the ABL, and occasional in-situ vertical profiles. The B-200 primarily sampled the ABL. For OCO-2 under flights, the C-130 flew at 8 km above ground with the B-200 flying in the ABL, both along the OCO-2 flight track. The existing in situ tower CO_2/CH_4 observing network was enhanced with five additional tower sites.

The mission delivered 2-3 times more high-quality lower tropospheric CO_2 and CH_4 observations than any previous airborne campaign.

Tower Sites

ACT-America utilized existing communications towers, filling gaps that existed in or near our three study regions in existing tower networks (Fig. 4). Specific sites were selected in science-critical locations based on tall tower and local Ethernet or cell phone data connection availability. Daily, automated data transfer to the Langley Atmospheric Science Data Center allowed for remote monitoring of instrument status and investigation planning.

NOTE: Data from 11 towers are provided, but not all towers have data for all years.

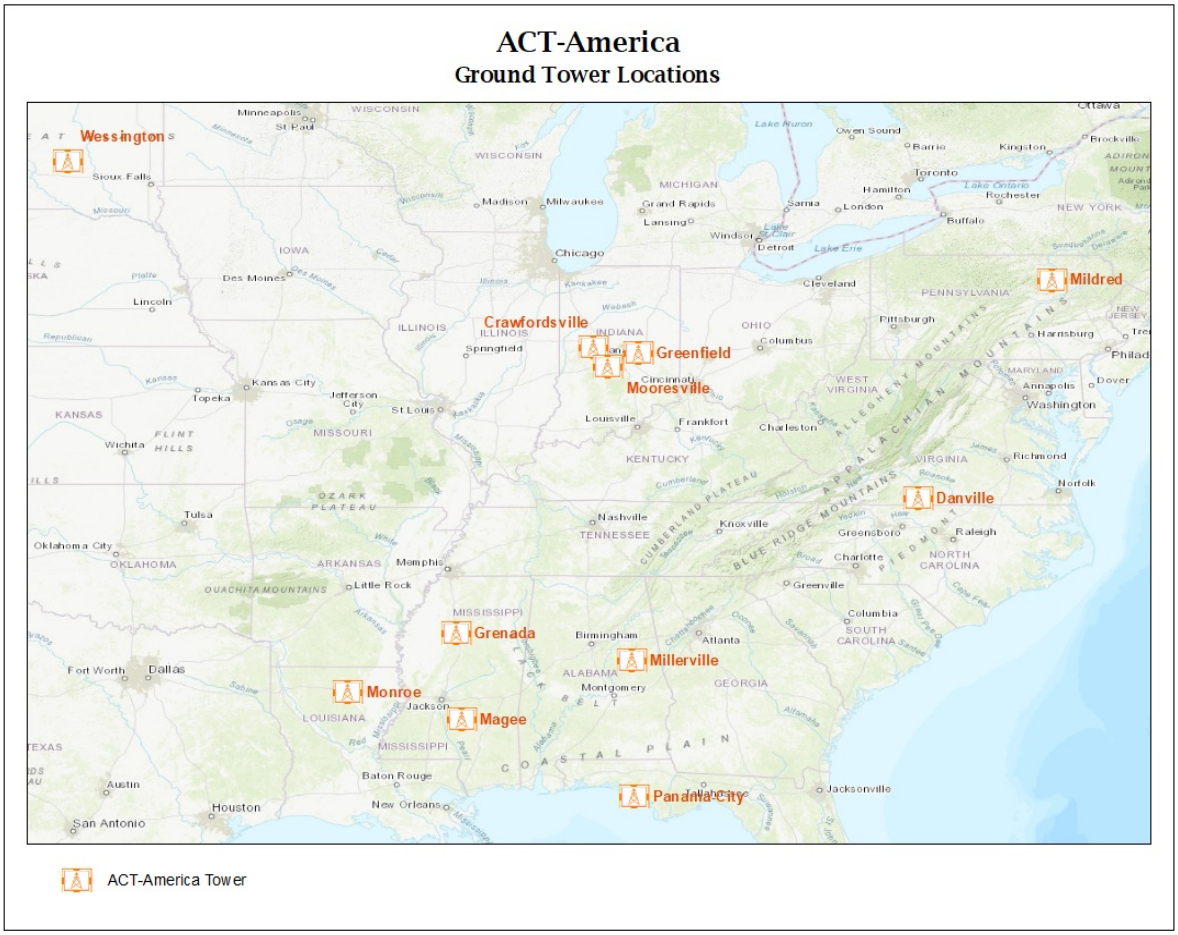

Figure 4. ACT-America atmospheric sampling tower locations.

Tower Instrumentation

Tower platforms utilized the Picarro G2301 CRDS for CO_2, CO, CH_4, and H_2O measurements (Fig. 5). Instruments reported raw data every 2-3 seconds, but these data points were not independent because of the mixing volume. Other L1 species and isotropic measurements were available from the Picarro G2301 CRDS, but not necessarily used in the ACT-America analysis.

Instrument specifications are found in the files *datasheet-g2301-crds-analyzer-co2-ch4-h2o-air-oct15.pdf* and *G2301-m+Manual+rev+2-11-11.pdf* that are included as companion files for this dataset.

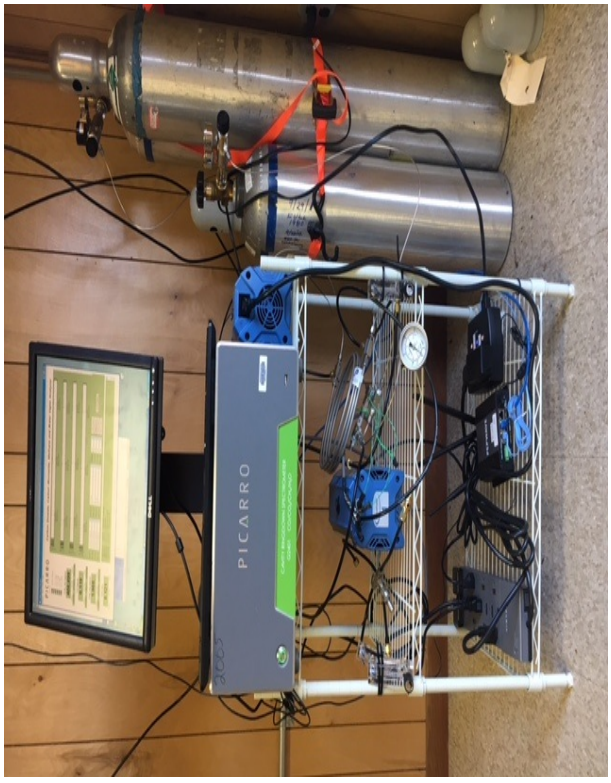

Figure 5. Instrumentation at one of the ACT-America tower sites.

6. Data Access

These data are available through the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

ACT-America: L1 Raw, Uncalibrated In-Situ CO2, CO, and CH4 Mole Fractions from Towers

Contact for Data Center Access Information:

- E-mail: uso@daac.ornl.gov
- Telephone: +1 (865) 241-3952

7. References

Digangi, J.P., Y. Choi, J.B. Nowak, and H.S. Halliday. 2017. ACT-America: L2 In Situ Atmospheric CO2, CO, CH4, and O3 Concentrations, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1556

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Richardson SJ, Miles NL, Davis KJ, Lauvaux T, Martins DK, Turnbull JC, et al. 2017. Tower measurement network of in-situ CO2, CH4, and CO in support of the Indianapolis FLUX (INFLUX) Experiment. Elem Sci Anth. 5:59. http://doi.org/10.1525/elementa.140