ACT-America: L2 In Situ Atmospheric CO2, CO, CH4, and O3 Concentrations, Eastern USA

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Documentation Revision Date: 2021-02-02

Dataset Version: 1.2

Summary

This dataset provides atmospheric carbon dioxide (CO2), carbon monoxide (CO), methane (CH4), water vapor (H2O), and ozone (O3) concentrations collected during airborne campaigns conducted by the Atmospheric Carbon and Transport-America (ACT-America) project. ACT-America's mission spanned 4 years and included five 6-week airborne campaigns covering all 4 seasons and 3 regions of the central and eastern United States. This dataset provides results from all five campaigns, including Summer 2016, Winter 2017, Fall 2017, Spring 2018, and Summer 2019. Two instrumented aircraft platforms, the NASA Langley Beechcraft B200 King Air and the NASA Goddard Space Flight Center's C-130H Hercules, were used to collect high-quality in situ measurements across a variety of continental surfaces and atmospheric conditions. CO2, CO, CH4, and H2O were collected with an infrared cavity ring-down spectrometer system (CRDS; Picarro Inc.). Ozone data were collected with a dual beam differential UV absorption ozone monitor (Model 205; 2B Technologies). Both aircraft hosted identical arrays of in situ sensors. Complete aircraft flight information including, but not limited to, latitude, longitude, altitude, and meteorological conditions are also provided.

ACT-America's overall mission spanned four years and included airborne 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 2,188 data files total; 1,094 files in netCDF (*.nc) format and 1,094 data files in ICARTT (*.ict) format. The netCDF variables are structured as GeoTrajectory along each flight segment. Each netCDF file has a corresponding file in ICARTT format that has identical trace gas data but the ICARTT file contains no aircraft navigation or meteorological data.

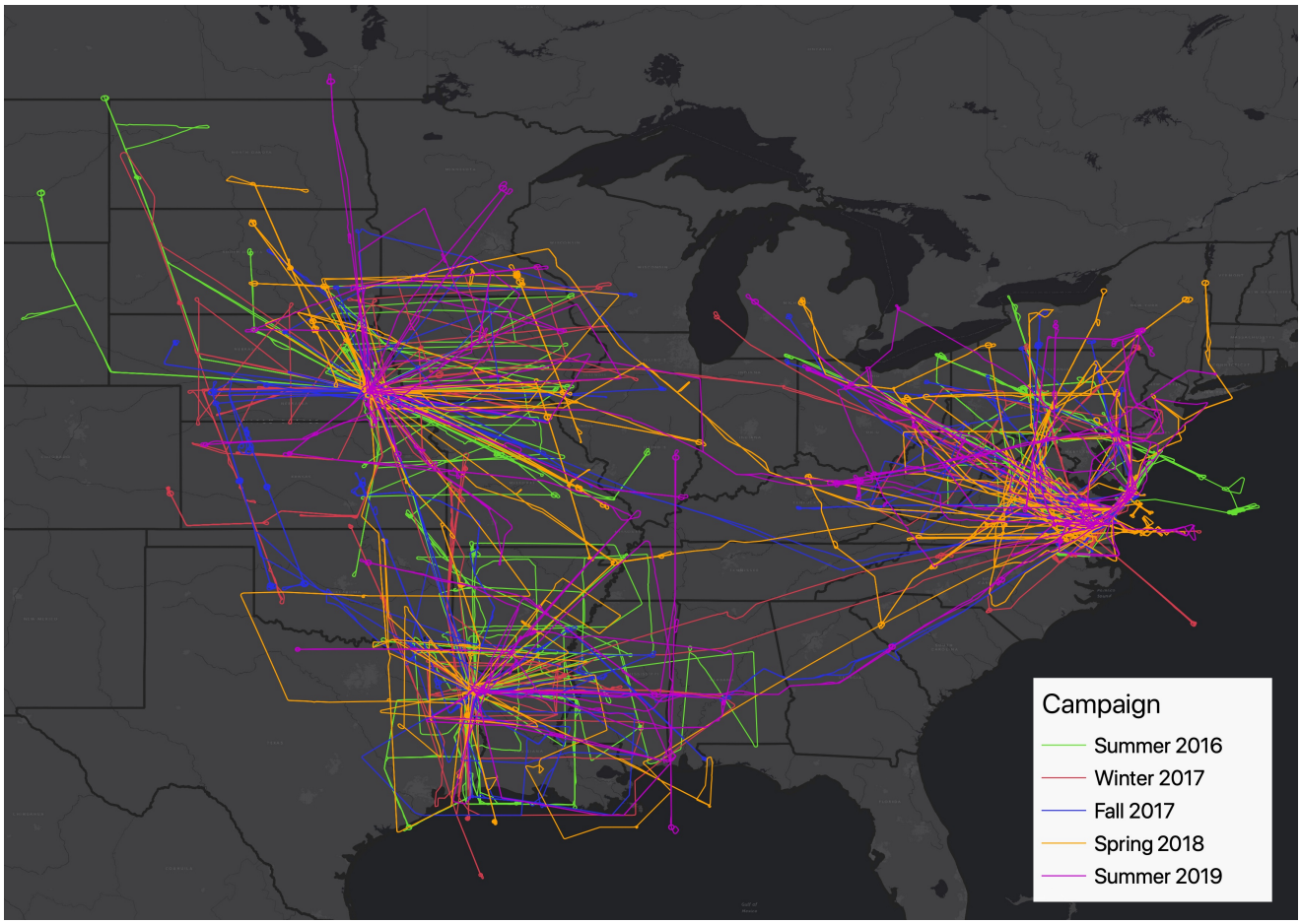

Figure 1. Flight paths for all five airborne campaigns of ACT-America. Flights were concentrated on three study areas: the northeast, south-central, and midwest regions of the United States.

Citation

DiGangi, J.P., Y. Choi, J.B. Nowak, H.S. Halliday, M.M. Yang, B.C. Baier, and C. Sweeney. 2018. 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

Table of Contents

1. Dataset Overview

This dataset provides atmospheric carbon dioxide (CO2), carbon monoxide (CO), methane (CH4), water vapor (H2O) and ozone (O3) concentrations collected during airborne campaigns conducted by the Atmospheric Carbon and Transport-America (ACT-America) project. ACT-America's mission spanned 4 years and included five 6-week airborne campaigns covering all 4 seasons and 3 regions of the central and eastern United States. This dataset provides results from all five campaigns, including Summer 2016, Winter 2017, Fall 2017, Spring 2018, and Summer 2019. Two instrumented aircraft platforms, the NASA Langley Beechcraft B200 King Air and the NASA Goddard Space Flight Center's C-130H Hercules, were used to collect high-quality in situ measurements across a variety of continental surfaces and atmospheric conditions. CO2, CO, CH4, and H2O were collected with an infrared cavity ring-down spectrometer system (CRDS; Picarro Inc.). Ozone data were collected with a dual beam differential UV absorption ozone monitor (Model 205; 2B Technologies). Both aircraft hosted identical arrays of in situ sensors. Complete aircraft flight information including, but not limited to, latitude, longitude, altitude, and meteorological conditions are also provided.

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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

Davis, K.J., M.D. Obland, B. Lin, T. Lauvaux, C. O'Dell, B. Meadows, E.V. Browell, J.P. DiGangi, C. Sweeney, M.J. McGill, J.D. Barrick, A.R. Nehrir, M.M. Yang, J.R. Bennett, B.C. Baier, A. Roiger, S. Pal, T. Gerken, A. Fried, S. Feng, R. Shrestha, M.A. Shook, G. Chen, L.J. Campbell, Z.R. Barkley, and R.M. Pauly. 2018. ACT-America: L3 Merged In Situ Atmospheric Trace Gases and Flask Data, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1593

Pal, S. 2019. ACT-America: Profile-based Planetary Boundary Layer Heights, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1706

Yang, M.M., J.D. Barrick, C. Sweeney, J.P. Digangi, and J.R. Bennett. 2018. ACT-America: L1 Meteorological and Aircraft Navigational Data. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1574

Acknowledgments

This work was supported by NASA EVS-2 grant number NNX15AG76G.

2. Data Characteristics

Spatial Coverage: Eastern and central United States

Spatial Resolution: Point measurements

Temporal Coverage: Periodic flights occurred during each intensive campaign.

Campaign	Beginning and Ending Dates
Summer 2016	2016-07-11 to 2016-08-28
Winter 2017	2017-01-21 to 2017-03-10
Fall 2017	2017-10-03 to 2017-11-13
Spring 2018	2018-04-12 to 2018-05-20
Summer 2019	2019-06-17 to 2019-07-27

Temporal Resolution: Approximately 1–2 seconds depending on instrument and flight.

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

Site	Northernmost Latitude	Southernmost Latitude	Westernmost Longitude	Easternmost Longitude
Eastern and Central United States	50.550	27.230	-106.494	-71.911

Data File Information

This dataset contains 2,188 data files total; 1,094 files in netCDF (*.nc) format and 1,094 data files in ICARTT (*.ict) format. The netCDF variables are structured as GeoTrajectory along each flight segment. Each netCDF file has a corresponding file in ICARTT format.

NetCDF files follow the standards of the NetCDF Climate and Forecast (CF) Metadata Conventions V1.6. Variables are structured as GeoTrajectory, where the observations for a flight segment are connected along a one-dimensional track in space and with time increasing monotonically along the track. These files contain gas concentrations and data from the respective aircraft's flight navigation system and meteorological instruments.

ICARTT files follow ICARTT File Format Standards V1.1. The ICARTT files contain the same gas concentration data as the netCDF files (i.e., Start_UTC, Stop_UTC, Mid_UTC, CH4_PIC_ppm) but no navigational or meteorological information.

Companion File Information

Additional information on the aircraft platforms deployed by ACT-America is provided in **Platform_B200.pdf** and **Platform_C130.pdf**.

Data File Details

File Naming Convention

Files are organized by instrument and aircraft for the flights on a given date. The naming convention is the same for netCDF and ICARTT files. Files are named according to the format **ACTAMERICA-<instrument>_<aircraft>_<YYYYMMDD>_<R#>_<L#>.<ext>** (e.g., ACTAMERICA-Ozone_B200_20160711_R1.nc), where

<instrument> is 'Ozone', 'PICARRO', 'PICARRO-CH4', 'PICARRO-CO', 'PICARRO-CO2', or 'PICARRO-H2O',
<aircraft> is either 'B200' or 'C130',
<YYYYMMDD> is the flight date in UTC time,
<R#> is the revision number of the data, where a higher number indicates a more recent revision (e.g., R1 = first revision),
<L#> is the launch number as some flights had more than one launch (e.g., L1 = first launch), and
<ext> is the file extension, either '.nc' (netCDF) or '.ict' (ICARTT).

Quality Flags

Missing values: All missing data are flagged with a value of -9999.

LOD flags: If any portion of the averaging period contains a Limit of Detection (LOD) value for a given measurement, the value is marked with a LOD flag.

- Measurements above the upper LOD are flagged with -7777.
- Measurements below the lower LOD are flagged with -8888.

The measurement upper and lower LOD values (or N/A) are provided in the netCDF global attributes and ICARTT header as applicable.

Table 1. Names and descriptions for variables in respective instrument files.

Instrument	Variable name	Units	Description
PICARRO (Summer 2016 campaign only)	CH4_PIC_ppmv, CO_PIC_ppmv, CO2_PIC_ppmv	parts per million volume	Methane mixing ratio, Carbon monoxide mixing ratio, Carbon dioxide mixing ratio
PICARRO-CH4	CH4_PIC_ppmv	parts per million volume	Methane mixing ratio
PICARRO-CO	CO_PIC_ppmv	parts per million volume	Carbon monoxide mixing ratio
PICARRO-CO2	CO2_PIC_ppmv	parts per million volume	Carbon dioxide mixing ratio
PICARRO-H2O	H2O_PIC_pct	percent	Water vapor volume mixing ratio
PICARRO-H2O	H2O_PIC_gkg	grams per kilogram	Water vapor mass mixing ratio
PICARRO-H2O	eH2O_PIC_mbar	millibars	Derived water vapor pressure
PICARRO-H2O	RHi_PIC_pct	percent	Derived relative humidity wrt ice
PICARRO-H2O	RHw_PIC_pct	percent	Derived relative humidity wrt liquid water
PICARRO-H2O	DP_PIC_degC	Celsius	Derived dew point
Ozone	O3_ppbv	parts per billion volume	Ozone mixing ratio

User Note: The ICARTT files contain the same gas concentration data as the netCDF files (e.g., Start_UTC, Stop_UTC, Mid_UTC, and CH4_PIC_ppm) but no navigational or meteorological information.

Table 2. Names and descriptions of navigation and meteorological variables. These variables are present in the netCDF files.

Variable name	Units	Description
time	seconds	seconds since 2016-01-01 00:00:00.0 UTC
time_bnds		boundary (start and end time) of each time step
Start_UTC	seconds	start UTC time of day for measurement
Stop_UTC	seconds	stop UTC time of day for measurement interval

Mid_UTC	seconds	mean UTC time of day of measurement interval
Flight_ID		Flight identification (aircraft and flight date)
Aircraft_Sun_Azimuth	degree	Platform azimuth angle
Aircraft_Sun_Elevation	degree	Solar elevation angle
Cabin_Pressure	millibars	Air pressure of cabin
Day_of_Year	day	Day of year starting Jan 1 UTC
Dew_Point	Celsius	Dew point temperature
Drift_Angle	degree	Drift angle
GPS_Altitude	meters	Global Positioning System altitude
GPS_Time	hours since 2016-01-01 00:00:00.0 UTC	Time
Ground_Speed	meters per second	Platform speed with respect to ground
Indicated_Air_Speed	knots	Indicated air speed
Latitude	degree north	Latitude, EPSG: 4326
Longitude	degree east	Longitude, EPSG: 4326
Mach_Number		Mach number
Mixing_Ratio	grams per kilogram	H2O mixing ratio
Part_Press_Water_Vapor	millibars	Water vapor partial pressure in air
Pitch_Angle	degree	Platform pitch angle
Potential_Temp	Celsius	Potential temperature
Pressure_Altitude	feet	Barometric altitude
Relative_Humidity	percent	Relative humidity
Roll_Angle	degree	Platform roll angle
Sat_Vapor_Press_H2O	millibars	H2O saturation vapor pressure of water
Sat_Vapor_Press_Ice	millibars	H2O saturation vapor pressure of ice
Solar_Zenith_Angle	degree	Solar zenith angle
Static_Air_Temp	Celsius	Static air temperature
Static_Pressure	millibars	Air pressure
Sun_Azimuth	degree	Solar azimuth angle
Total_Air_Temp	Celsius	Total air temperature
Track_Angle	degree	Track angle
True_Air_Speed	knots	Platform speed with respect to air
True_Heading	degree	Platform yaw angle
Vertical_Speed	feet per minute	Vertical speed
Wind_Direction	degree	Wind direction
Wind_Speed	meters per second	Wind speed
Altitude_AGL_m	meters	Aircraft altitude above ground level
Ground_Elevation_m	meters	Ground elevation above mean sea level

Data Center Processing

The ORNL DAAC created netCDF files for each of the provided ICARTT files. Aircraft navigation and meteorological information were added to the netCDF files from Pal (2019) for B-200 flights and Yang et al. (2018) for C-130 flights.

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.

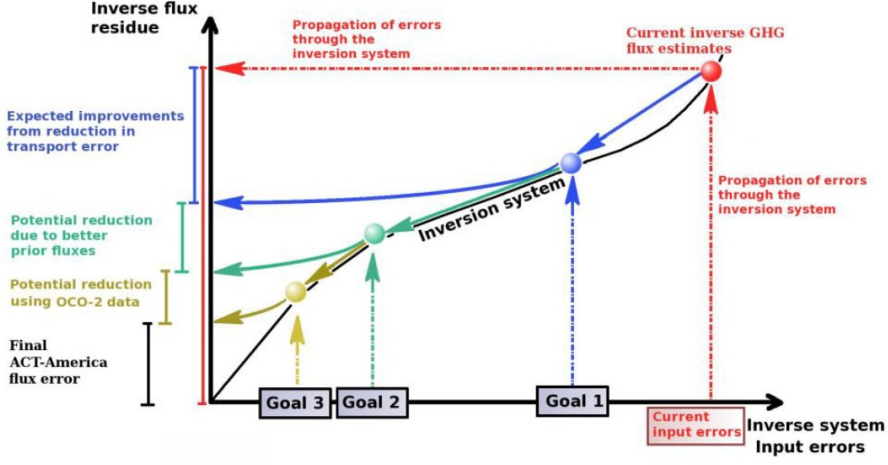

Figure 2. A schematic showing ACT-America mission goals.

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

Picarro G2301

These instruments exceed the precision requirements of the baseline science objective for the mission for all four gases (Karion et al., 2013). Accuracies of 0.2 ppm for CO_2 and 2 ppb for CH_4 also exceed mission accuracy requirements of 1 ppm for CO_2 and 4 ppb for CH_4.

2B Technologies Model 205

The O_3 monitor has been previously flown on tropospheric chemistry field missions and meets the accuracy and precision requirements for the baseline science objectives of the mission (Bertschi et al., 2004).

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

Instrument	Platform	Technique	Species/Parameter	Instrument Precision (Averaging Time)	STM Precision Requirement [over 20 km (~130 sec) unless otherwise noted]
2B Technologies Model 205	C-130H, B-200	Laser Spectrometer	O_3	1 ppb (10 sec)	8 ppb
Picarro G2301	Tower	Cavity Ring-Down Spectroscopy	CO_2, CH_4	≤ 0.07 ppm CO_2 ≤ 0.5 ppb CH_4 (both 5 sec)	1 ppm hourly CO_2 4 ppb hourly CH_4

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 (Crisp et al., 2004, Crisp et al., 2008).

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.

Flight Plans

Data from the fair-weather flights are intended to quantify regional CO_2 and CH_4 fluxes, and to evaluate fair weather atmospheric C transport processes. The flight pattern is designed to provide extensive sampling of the ABL and lower FT in source/sink regions, meeting the requirements for the fair weather investigation. The C-130 aircraft will fly a U-shape pattern with flight legs perpendicular to the wind, sampling FT and ABL properties downwind of the sources and sinks of C. The C-130 will fly at roughly two times the midday ABL depth, (3–4 km above ground level) with periodic descents and ascents (5–10 times in a 6–8 hr flight) to sample the ABL. Although clear sky conditions will be targeted, the C-130 will conduct more profiling if low-altitude clouds interfere with the remote sensors. The B-200 aircraft will partake in two flights per day and will sample a subset of the C-130 flight path

focusing on long transects in the ABL with periodic ascents to the FT. The two aircraft will operate over the same time period, but precise coordination is not required.

Data from stormy-weather flights will be used in combination with the data from fair-weather flights to evaluate the transport of C in the mid-latitudes. The flight plans include flight legs parallel to and crossing frontal boundaries at two or more altitudes, and crossing the frontal zone at two or more locations, meeting the requirements for the stormy weather investigation.

The pattern for the OCO-2 inter-comparison flights is designed to obtain data to evaluate the degree to which OCO-2 column CO_2 measurements capture true spatial variability in column CO_2 content over the continents. Two OCO-2 under flights will be conducted during each campaign and will be selected to cover varying surface reflectance, topography, and aerosol and cloud cover, all possible sources of bias in the OCO-2 measurements. The C-130 flights will be 1,000 km in length and flown at 8 km (28 ft) altitude to maximize the fraction of the atmospheric column sampled by the MFLL. The B-200 aircraft will sample a shorter (~360 km) leg in the ABL, often the largest source of variability in column CO_2. The B-200 flight will be centered with the C-130 and both aircraft will be vertically stacked during the OCO-2 overpass.

Airborne Instruments

ACT-America deployed high-quality, field-tested trace gas and meteorological instruments. For this dataset, the C-130 aircraft carried continuous CO_2/CH_4/H_2O/CO analyzers, a cavity ring-down spectroscopy (CRDS) instrument (Picarro Inc.) used for rapid measurement of trace gas mole fractions (Crosson, 2008), and continuous O_3 monitors. The B-200 has the same in situ sensors except for winds.

Picarro G2301

The C-130 and B-200 both have Picarro instruments. The Picarro instruments have been extensively tested on aircraft flights (Karion et al., 2013; Mays et al., 2009; Turnbull et al., 2011). Picarro analyzers are based on Wavelength-Scanned Cavity Ring Down Spectroscopy (WS-CRDS), a time-based measurement utilizing a near-infrared laser to measure a spectral signature of molecular absorption. Gas flows through a 35-cc optical cavity with an effective path length of up to 20 km and pressure of 140 Torr. Extremely stable and high-precision measurements are achieved through cavity temperature, pressure, and wavelength laser frequency control to better than 0.002°C, 0.00003 atm, and 1 MHz, respectively. Aircraft instruments are similar to surface-based sensors, but use faster flow rates, solid-state data storage, and additional vibration isolation. These instruments exceed the precision requirements of the baseline science objectives for all four gases (Karion et al., 2013). Accuracies of 0.2 ppm for CO_2 and 2 ppb for CH_4 (Karion et al., 2013) also exceed mission accuracy requirements of 1 ppm for CO_2 and 4 ppb for CH_4.

2B Technologies Model 205

The Model 205 O_3 monitor uses two ultraviolet beams in two cells to simultaneously measure O_3-scrubbed air and unscrubbed air. This model has been approved by the Environmental Protection Agency as a Federal Equivalent Method (FEM) and is the fastest UV-based O_3 monitor available. The O_3 monitor has been previously flown on tropospheric chemistry field missions and meets the accuracy and precision requirements laid out in the STM (Bertschi et al., 2004).

6. Data Access

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

ACT-America: L2 In Situ Atmospheric CO2, CO, CH4, and O3 Concentrations, Eastern USA

Contact for Data Center Access Information:

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

7. References

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8. Dataset Revisions

Version	Release Date	Description of Changes
1.2	2021-02-02	Updated earlier campaign data and added Summer 2019 campaign data.
1.1	2019-03-27	Updated earlier campaign data and added Fall 2017 and Spring 2018 campaign data.
1.0	2018-06-26	Initial data added for Summer 2016 and Winter 2017 campaigns.