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ACT-America: L3 Merged In Situ Atmospheric Trace Gases and Flask Data, Eastern USA

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Summary

This dataset provides merged data products acquired during flights over the central and eastern United States as part of the Atmospheric Carbon and Transport - America (ACT-America) project. Two 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. The merged data products are composed of continuous in situ measurements of atmospheric carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), ozone (O₃), and ethane (C₂H₆, B200 aircraft only) that were averaged to uniform intervals and merged with aircraft navigation and meteorological variables as well as trace gas concentrations from discrete flask samples collected with the Programmable Flask Package (PFP). These merged data products provide integrated measurements at intervals useful to the modeling community for studying the transport and fluxes of atmospheric carbon dioxide and methane across North America.

There are a total of 1256 files in this dataset. There are 628 data files in NetCDF (*.nc) file format and 628 data files in ICARTT (*.ict) file format. Note that files in both formats contain the same atmospheric gas concentration data but the netCDF files contain additional variables (e.g., metadata flag information) and consistent variable names across campaigns and aircrafts.

This dataset currently includes results from the Summer 2016, Winter 2017, Fall 2017, Spring 2018, and Summer 2019 campaigns.

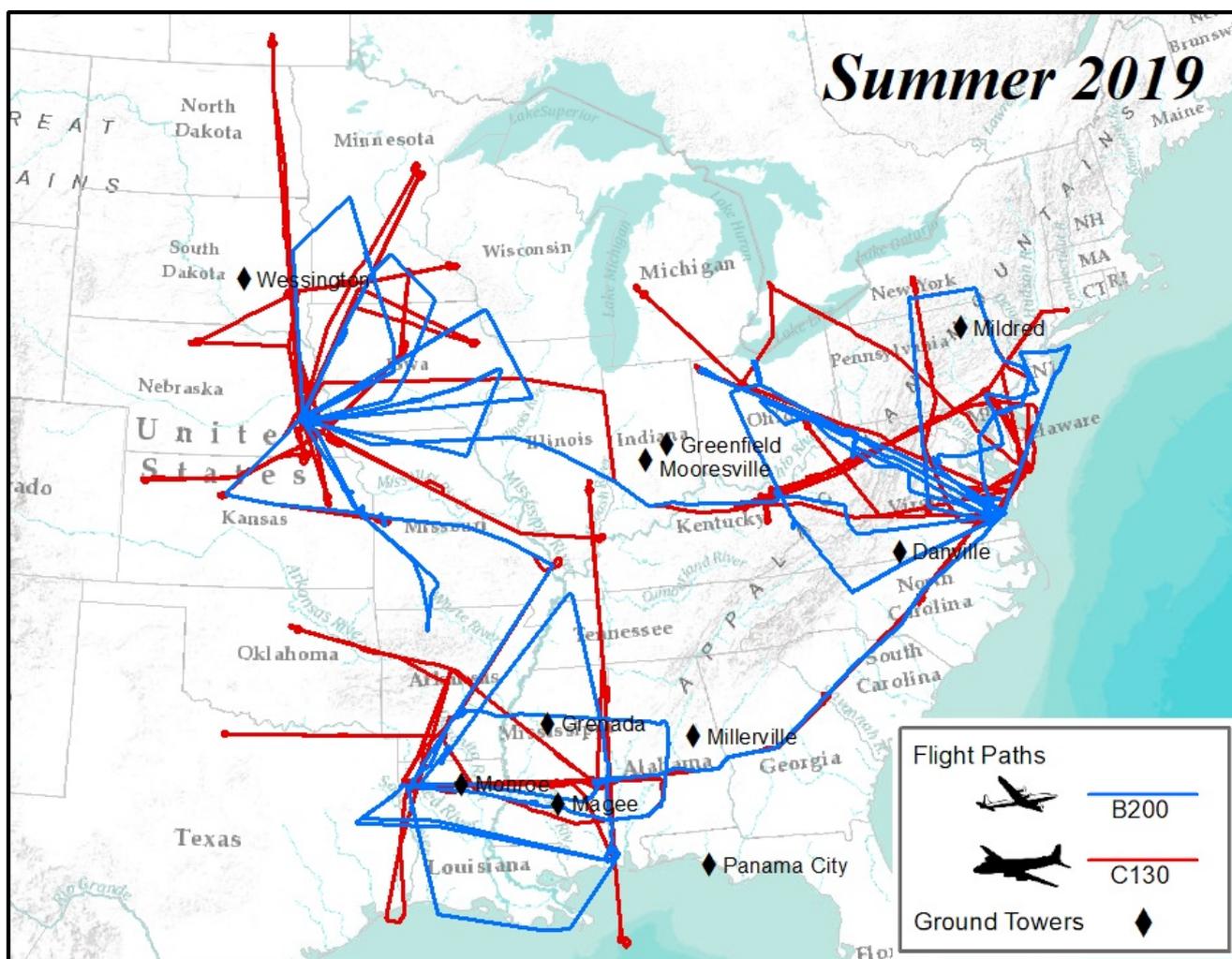


Figure 1. ACT-America 2019 summer airborne campaign showing the flight paths for the two aircrafts and location of ground towers. Flights were concentrated on three study domains: northeast, south-central, and midwest regions of the United States.

Citation

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>

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1. Dataset Overview

This dataset provides three merged data products acquired during flights over the central and eastern United States as part of the Atmospheric Carbon and Transport - America (ACT-America) project. Two 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. The merged data products are composed of continuous in situ measurements of atmospheric carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), ozone (O₃), and ethane (C₂H₆, B200 aircraft only) that were averaged to uniform intervals and merged with trace gas concentrations from discrete flask samples collected with the Programmable Flask Package (PFP) and the aircraft navigation and meteorological variables. These merged data products provide integrated measurements at intervals useful to the modeling community for studying the transport and fluxes of atmospheric carbon dioxide and methane across North America.

Project: [Atmospheric Carbon and Transport \(ACT-America\)](#)

The ACT-America, or Atmospheric Carbon and Transport - America, project is 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. Each flight campaign will measure how weather systems transport these greenhouse gases. Ground-based measurements of greenhouse gases were also collected. Better estimates of greenhouse gas sources and sinks are needed for climate management and for prediction of future climate.

Related Datasets

The original Level 2 data from the portable flask package system, cavity ring-down spectrometers, and ozone instruments are available in their native sampling intervals as independent 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>

Sweeney, C., B. Baier, J.B. Miller, P. Lang, B. Miller, S. Lehman, S. Englund-Michel, and M.M. Yang. 2018. ACT-America: L2 In Situ Atmospheric Gas Concentrations from Flasks, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/1575>

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>

2. Data Characteristics

Spatial Coverage: Flights over eastern and central United States

Spatial Resolution: Point measurements

Temporal Coverage: Periodic flights took place 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	2019-06-11 to 2019-07-27

Temporal Resolution: 1-seconds, 5-seconds, and intervals coinciding with flask samples

Study Area: (These coordinates are the approximate locations of the study sites and may not match the extent of the data files. All latitude and longitude are given in decimal degrees.)

Site	Northern Extent	Southern Extent	Western Extent	Eastern Extent
Central and Eastern United States	50.55	27.230	-106.494	-72.662

Dataset Information

There are a total of 1256 files in this dataset. Files are organized by flight date, aircraft (B200 and C130), and the time interval on which the data were merged (1 or 5 seconds or flask sampling intervals).

Format: NetCDF

There are 628 data files in NetCDF trajectory version 4 (*.nc) format following [CF Conventions 1.6](#). NetCDF files are structured as GeoTrajectory files, where the observations for a flight segment are connected along a one-dimensional track in space, with time increasing monotonically along the track.

These files contain gas concentrations and data from the respective aircraft's flight navigation system. The flight and altitude data were imported from the ACT-America P3-B Data System PDS (for B200 flights) and Housekeeping data (for C130 flights). Flight variables are listed in **Table 1** of the **Data Dictionary** section below.

Format: ICARTT

There are 628 data files in ICARTT file format (*.ict) following the [ICARTT standard](#). The files contain the same atmospheric gas concentration data as the NetCDF files, but no metadata flag information.

The structure of the merged data products is described in the table below.

Data Product	Reporting Frequency	File Organization	Merge Protocol - Continuous	Merge Protocol Discrete
Continuous one-second merge	1-second	For both NetCDF and ICARTT file formats, files are organized by: aircraft (B-200 or C-130), flight date, revision number, and optionally flight segment (number) for flights with more than one segment.	L2 data from Picarro CRDS and ozone monitoring instruments (2B Technologies) were averaged to 1-second intervals	PPF sample results were added to the 1-second continuous reporting time observation that was nearest the middle of the flask sample collection period
Continuous 5-second merge	5-seconds	For both NetCDF and ICARTT file formats, files are organized by: aircraft (B-200 or C-130), flight date, revision number, and optionally flight segment (number) for flights with more than one segment.	L2 data from Picarro CRDS and ozone monitoring instruments (2B Technologies) were averaged to 5-second intervals	PPF sample results were added to the 5-second continuous reporting time observation that was nearest the middle of the flask sample collection period
Discrete Flask-based Merge	Variable; total PPF fill time	For both NetCDF and ICARTT file formats, files are organized by: aircraft (B-200 or C-130), flight date, revision number, and optionally flight segment (number) for flights with more than one segment.	L2 data from Picarro CRDS and ozone monitoring instruments (2B Technologies) were averaged to the 15-second interval surrounding each flask sample	Flask samples are presented at their native temporal resolution

Readme files for each of the merged products were also generated and are provided as companion files. The methods used to combine the data points for each time interval are described in Section 3 of the documentation for the [Toolsets for Airborne Data](#) (NASA ASDC), also included as a companion file (*TAD-Documentation.pdf*).

Data Sources

Atmospheric Trace Gas Analyses

- the two Cavity Ring-Down Spectrometers (CRDS; Picarro Inc.): PICARRO G2301-m on C-130 and PICARRO G2401-m on B-200
- the continuous ozone monitoring instrument (2B Technologies)
- the Compact Atmospheric Multi-Species Spectrometer (CAMS-2; B-200 flights only)
- results of Portable Flask Package (PPF) sample analyses

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>

Sweeney, C., B. Baier, J.B. Miller, P. Lang, B. Miller, S. Lehman, S. Englund-Michel, and M.M. Yang. 2018. ACT-America: L2 In Situ Atmospheric Gas Concentrations from Flasks, Eastern USA. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/1575>

Flight Navigational and Meteorological Data

- flight and altitude data from the ACT-America P3-B Data System PDS (for B-200 flights)
- flight and altitude data from Housekeeping data (for C-130 flights)

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>

Data Quality Flags

The 1- and 5-second merged data products were generated by averaging the measurement values across each time interval.

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

- measurements above the upper LOD are flagged with -777777;
- measurements below the lower LOD are flagged with -888888;
- all missing data are flagged with a value of -999999;

File Naming Convention:

Variable names have been modified from those in the source datasets to include the instrument; e.g. CH₄_MoleFraction -> CH₄_MoleFraction_PFP

ACTAMERICA-*<interval>*-*<aircraft>*-merge_*<YYYYMMDD>*_*<revision number>*..*<ext>*

where:

<interval> : time interval of the merged measurements; *mrg01* = 1-second, *mrg05* = 5-second, *mrgPFP* = Flask intervals

<aircraft> : either *B200* or *C130*

<YYYYMMDD> : flight date (UTC)

<revision number> : revision number of the data. A higher number indicates a more recent revision; e.g. R1 = revision 1

<ext> : file extension; either *nc* (NetCDF) or *ict* (ICARTT)

Data Dictionary

The files contain atmospheric trace gas concentration data **and** data from the respective aircraft's flight navigation system.

Table 1. Name, instrument, description, and units for each of the variables in the merged in the NetCDF files.

Variable name	Description	Units ¹
Instrument: Portable Flask Package		
BENZ_MoleFraction_PFP	benzene mole fraction	ppt
C2F6_MoleFraction_PFP	hexafluorethane mole fraction	ppt
C2H2_MoleFraction_PFP	acetylene mole fraction	ppt
C2H6_MoleFraction_PFP	ethane mole fraction	ppt
C3H8_MoleFraction_PFP	propane mole fraction	ppt
CF4_MoleFraction_PFP	carbon tetrafluoride mole fraction	ppt
CH2BrCl_MoleFraction_PFP	bromochloromethane mole fraction	ppt
CH3I_MoleFraction_PFP	methyl iodide mole fraction	ppt
CH4C13_MoleFraction_PFP	C-13 of CH4 mole fraction	per mil
CH4_MoleFraction_PFP	methane mole fraction	ppb
CHLF_MoleFraction_PFP	chloroform mole fraction	ppt
CO2C14_MoleFraction_PFP	C-14 of CO2 mole fraction	per mil
CO2_MoleFraction_PFP	carbon dioxide mole fraction	ppm
CO_MoleFraction_PFP	carbon monoxide mole fraction	ppb
DIBR_MoleFraction_PFP	dibromomethane mole fraction	ppt
DICL_MoleFraction_PFP	dimethyl chloride mole fraction	ppt
F113_MoleFraction_PFP	CFC113 mole fraction	ppt
F115_MoleFraction_PFP	CFC115 mole fraction	ppt
F11B_MoleFraction_PFP	F11 mole fraction	ppt
F125_MoleFraction_PFP	pentafluoroethane mole fraction	ppt
F134A_MoleFraction_PFP	Tetrafluoroethane mole fraction	ppt
F13_MoleFraction_PFP	F13 mole fraction	ppt

F143a_MoleFraction_PFP	1-1-1-trifluoroethane mole fraction	ppt
F152A_MoleFraction_PFP	1-1-difluoroethane mole fraction	ppt
F227e_MoleFraction_PFP	F227 mole fraction	ppt
F236fa_MoleFraction_PFP	F236fa mole fraction	ppt
F23_MoleFraction_PFP	fluoroform mole fraction	ppt
F32_MoleFraction_PFP	F32 mole fraction	ppt
F365m_MoleFraction_PFP	pentafluorobutane mole fraction	ppt
FC12_MoleFraction_PFP	FC12 mole fraction	ppt
H1211_MoleFraction_PFP	halon 1211 mole fraction	ppt
H1301_MoleFraction_PFP	halon 1301 mole fraction	ppt
H2402_MoleFraction_PFP	halon 2402 mole fraction	ppt
H2_MoleFraction_PFP	hydrogen mole fraction	ppb
HF133a_MoleFraction_PFP	HF133a mole fraction	ppt
HF22_MoleFraction_PFP	HF22 mole fraction	ppt
MCFA_MoleFraction_PFP	methyl chloroform mole fraction	ppt
MEBR_MoleFraction_PFP	methyl bromide mole fraction	ppt
MECL_MoleFraction_PFP	methyl chloride mole fraction	ppt
N2O_MoleFraction_PFP	nitrous oxide mole fraction	ppb
OCS_MoleFraction_PFP	carbonyl sulfide mole fraction	ppt
P218_MoleFraction_PFP	P218 mole fraction	ppt
PCE_MoleFraction_PFP	perchloroethylene mole fraction	ppt
SF6_MoleFraction_PFP	sulfur hexafluoride mole fraction	ppt
SO2F2_MoleFraction_PFP	sulfuryl fluoride mole fraction	ppt
TCE_MoleFraction_PFP	trichloroethylene mole fraction	ppt
TOL_MoleFraction_PFP ¹¹	toluene mole fraction	ppt
iC4H10_MoleFraction_PFP	isoButane mole fraction	ppt
iC5H12_MoleFraction_PFP	isoPentane mole fraction	ppt
nC4H10_MoleFraction_PFP	neoButane mole fraction	ppt

nC5H12_MoleFraction_PFP	neoPentane mole fraction	ppt
nC6H14_MoleFraction_PFP	n-Hexane mole fraction	ppt
Instrument: Picarro CRDS		
CH4_DryMoleFraction_PICARRO	Methane dry mole fraction	ppm
CO2_DryMoleFraction_PICARRO	carbon dioxide dry mole fraction	ppm
CO_DryMoleFraction_PICARRO	Carbon monoxide dry mole fraction	ppm
Dewpoint_PICARRO	dew point	K
H2O_MassMixingRatio_PICARRO ⁶	Water vapor mass mixing ratio	g kg-1
H2O_VaporPressure_PICARRO ⁶	Derived water vapor pressure	hPa
H2O_VolMixingRatio_PICARRO ⁶	Water vapor volume mixing ratio	percent
RHi_PICARRO ⁶	Derived relative humidity wrt ice	percent
RHw_PICARRO ⁶	Derived relative humidity wrt liquid water	percent
Instrument: CAMS2 Spectrometer⁴		
C2H6_MixingRatio_CAMS2	C2H6 mixing ratio by volume	ppbv
Instrument: Cloud Physics Lidar⁵		
MLH-AMSL_CPL	derived mixed layer height in ASL	m
GroundHeight-AMSL_CPL	derived ground height above MSL	m
Instrument: 2B Technologies Continuous O3		
O3_DryMoleFraction	ozone mole fraction	ppb
Instrument: In Situ Quantum Cascade Laser Spectrometer (QCLS) ⁷		
C2H6_MixingRatio_QCLS	C2H6 dry mixing ratio	ppbv
Aircraft navigation and meteorological variables		
ALTP	pressure altitude	m
AircraftSunAzimuth	aircraft sun azimuth	degree
AircraftSunElevation	aircraft sun elevation	degree
CabinPressure	cabin pressure	hPa
Dewpoint_Nav	dew point	K

DifferentialPressure ⁸	differential pressure	hPa
DriftAngle ⁹	drift angle	degree
GPS_ALT	global positioning system altitude	m
GRD_SPD	ground speed	m s-1
H2O_MixingRatio_Nav	H2O mixing ratio	g kg-1
H2O_RelativeHumidity_Nav	relative humidity	percent
H2O_SatVaporPressureIce_Nav	H2O sat vapor pressure ice	hPa
H2O_SatVaporPressureWater_Nav	H2O sat vapor pressure water	hPa
H2O_VaporPressure_Nav	H2O vapor pressure	hPa
HDG	true heading	degree
IAS	indicated air speed	m s-1
LATITUDE	latitude	degree_north
LOCAL_SUN_TIME	local sun time	h
LONGITUDE	longitude	degree_east
MachNumber	mach number	1
PITCH	pitch angle	degree
PRESSURE	static pressure	hPa
PotentialTemp_Nav	potential temperature	K
Radar_ALT ³	radar altitude	m
ROLL	roll angle	degree
SZA	solar azimuth angle	degree
SolarZenithAngle	solar zenith angle	degree
StaticPressure ¹⁰	static pressure	hPa
SunAzimuth	sun azimuth	degree
TAS	true air speed	m s-1
TEMPERATURE	static air temperature	K
THETA	potential temperature	K

TRK	track angle	degree
TotalAirTemp	total air temperature	K
VerticalSpeed	vertical speed	m s-1
U_WINDS	U wind direction	m s-1
V_WINDS	V wind direction	m s-1
Wind_Direction	wind direction	degree
Wind_Speed	wind speed	m s-1
Metadata flag information²		
Air_flag	Warm/Cold air flag	
BL_FT_flag	Boundary layer or free troposphere flag	
Flight_flag	Flight pattern flag	
Maneuver_flag	Maneuver flag	
Maneuver_flagQC	Maneuver flag QC	
Extracted ground elevation		
Altitude_AGL	Aircraft altitude above ground level from Google Maps API	m
GroundElevation-AMSL_GoogleMaps	ground elevation above mean sea level from Google Maps API	m

¹ ppm: parts per million; ppb: parts per billion; ppt: parts per trillion; ppbv: parts per billion by volume;

² Metadata flag information is only available for 5-second merge files.

³ Radar altitude is only available for the 2018 Spring and 2019 Summer campaigns on C-130 aircraft.

⁴ CAMS2 instrument on B-200 aircraft only.

⁵ CPL instrument on C-130 aircraft only.

⁶ H2O PICARRO variables are available starting Winter 2017 on C-130 aircraft only.

⁷ QCLS instrument flown on C-130 aircraft for the 2019 Summer campaign only.

⁸ DifferentialPressure available B-200 aircraft only.

⁹ DriftAngle not available for 2017 and 2019 campaigns.

¹⁰ StaticPressure only available for 2016 and 2018 campaigns.

¹¹ TOL_MoleFraction_PFP not available for 2019 campaign.

3. Application and Derivation

ACT-America, or Atmospheric Carbon and Transport – America, will conduct five airborne campaigns across three regions in the eastern United States to study the transport 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 will accurately and precisely quantify 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 addresses the three primary sources of uncertainty in atmospheric inversions — transport error, prior flux uncertainty and limited data density.

ACT-America will advance 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 (CO₂) and methane (CH₄) are poorly known at regional to continental scales. ACT-America will enable and demonstrate a new generation of atmospheric inversion systems for quantifying CO₂ and CH₄ sources and sinks.

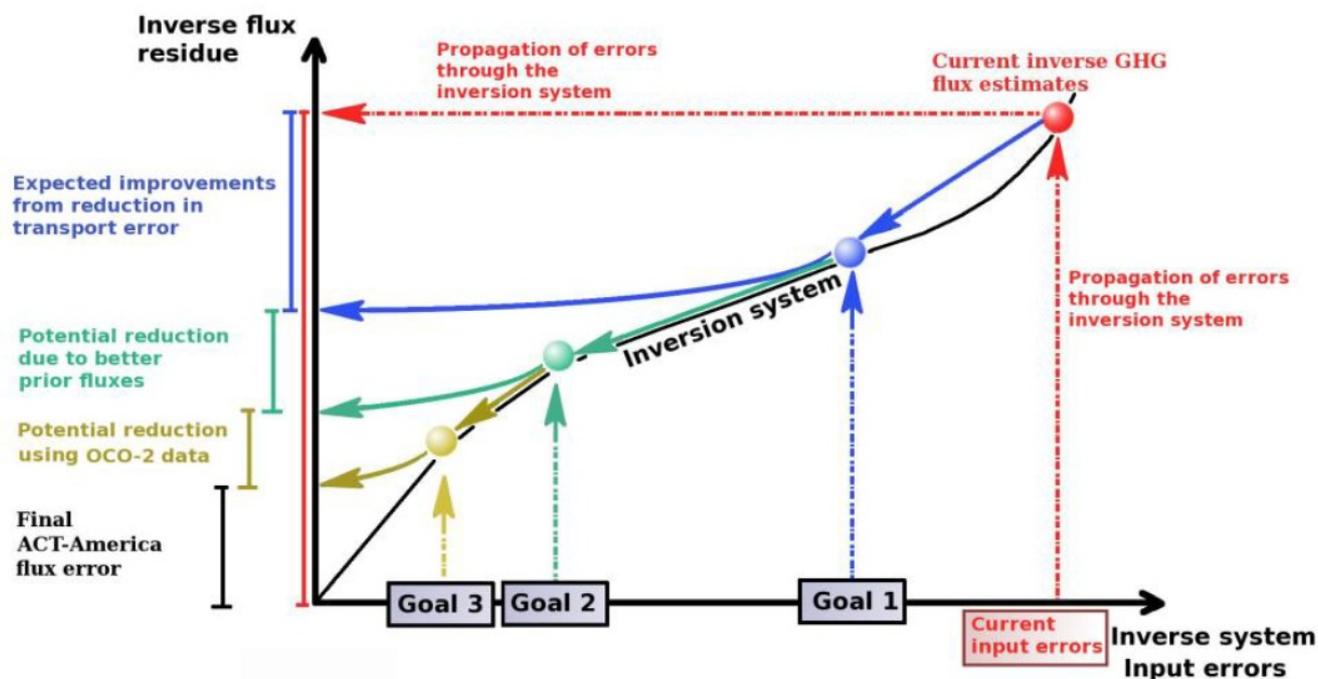


Figure 2. A schematic showing ACT-America project goals.

ACT-America Goals:

1. To quantify and reduce atmospheric transport uncertainties.
2. To improve regional-scale, seasonal prior estimate of CO₂ and CH₄ fluxes.
3. To evaluate the sensitivity of Orbiting Carbon Observatory (OCO-2) column measurements to regional variability in tropospheric CO₂.

ACT-America will achieve these goals by deploying airborne and ground-based platforms to obtain data that will be combined with data from existing measurement networks and integrated with an ensemble of atmospheric inversion systems. Aircraft instrumented with remote and in situ sensors will observe how mid-latitude weather systems interact with CO₂ and CH₄ sources and sinks to create atmospheric CO₂/CH₄ distributions. A model ensemble consisting of a mesoscale atmospheric transport model with multiple physics and resolutions options nested within global inversion models and surface CO₂/CH₄ flux ensembles will be used to predict atmospheric CO₂ and CH₄ distributions.

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

4. Quality Assessment

Picarro continuous CO₂/CH₄/H₂O/CO: 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 CO₂ and 2 ppb for CH₄ also exceed mission accuracy requirements of 1 ppm for CO₂ and 4 ppb for CH₄.

2B Technologies Continuous O₃: The O₃ 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).

Within the data, nodata and out-of-range values are provided in the dataset as described. 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]
MFL	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 ₂ O	≤ 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

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

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

See additional instrument quality control discussion here: <https://www.esrl.noaa.gov/gmd/ccgg/aircraft/qc.html>

5. Data Acquisition, Materials, and Methods

ACT-America Overview

The eastern half of the United States, a region that includes a highly productive biosphere, vigorous agricultural activity, extensive gas and oil extraction, 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. Flights will concentrate observations on three study domains: Northeast, South-central, and Midwest.

ACT-America will deploy the NASA C-130 and B-200 aircraft to measure atmospheric CO₂ and CH₄ in the atmospheric boundary layer (ABL) and free troposphere (FT). The mission proposes a total of 70 science flights, 528 hours for the C-130 and 396 hours for the B-200, 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 will fly at 3-8 km above ground, collecting in situ measurements in the lower FT, remotely sensed, column-averaged CO₂ measurements focused on the ABL, and occasional in situ vertical profiles. The B-200 will primarily sample the ABL. For OCO-2 underflights, the C-130 will fly 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 CO₂/CH₄ observing network will be enhanced with five additional tower sites.

The mission will deliver 2-3 times more high-quality lower tropospheric CO₂ and CH₄ observations than any previous airborne campaign.

Flight Plans

Data from the fair-weather flights are intended to quantify regional CO₂ and CH₄ 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 (AGL)) with periodic descents and ascents (5 to 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 CO₂ measurements capture true spatial variability in column CO₂ 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 1000 km in length and flown at 8 km (28 kft) altitude to maximize the fraction of the atmospheric column sampled by the MFL. The B-200 aircraft will sample a shorter (~360 km) leg in the ABL, often the largest source of variability in column CO₂. 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. This dataset includes measurements from discrete air samples captured by the onboard flask sampling system, in situ measurements of trace gas mole fractions from a cavity ring-down spectroscopy (CRDS) instrument (Picarro Inc.), and ozone measurements by a continuous O₃ monitor (2B Technologies), as well as in situ pressure, temperature and wind measurements.

Flask air sampling system

The two air-sampling devices, the Programmable Flask Package (PFP) and Programmable Compressor Package (PCP) systems, are used routinely on aircraft as part of the NOAA/ESRL Greenhouse Gas Reference network (Sweeney et al., 2015).



Figure 4. Flask sampling system for aircraft measurements. Left: Programmable Flash Package (PFP) containing 12 flasks. Right: Programmable Compressor Package (PCP) containing pumps for pressurizing the flasks. (Image courtesy: <http://www.esrl.noaa.gov/gmd/ccgg/aircraft/sampling.html>)

A typical sampling routine uses one PCP and one or more PFP(s) that are pre-programmed with a flight-specific sampling plan of target altitudes for each sample. Sampling is timed to coincide with the overflight of a ground site of interest, or when interesting geophysical conditions are encountered. A map of flask sample locations is depicted in Figure 1. The PCP is connected to an LED display that communicates target sampling altitudes to the pilot. The pilot maintains the aircraft at a consistent altitude for the duration of each sample collection, typically under 40 seconds. For each sample, the inlet line and compression manifold are flushed with about 5 liters of ambient air. Valves on both ends of the current flask are then opened and the flask is flushed with about 10 more liters of ambient air to displace the dry, low CO₂ fill gas with which the flasks are shipped. The sample flush air is measured by a mass flow meter to ensure that a sufficient volume passes through the manifold and flask before the downstream valve is closed and pressurization begins. Sample flush volumes and fill pressures during sampling are recorded by the data logger, along with ambient temperature, pressure, and relative humidity. GPS position and time stamp are also recorded with each sample.

The PFP samples were sent back to NOAA/ESRL in Boulder, CO, for analysis of trace gases. The gases fall into four broad categories including: greenhouse gases, carbon isotopes, halocarbons and hydrocarbons. Quantities of CO₂ in flask air samples were detected using a non-dispersive infrared analyzer and reported in parts per million (ppm). Because detector response is non-linear in the range of atmospheric levels, ambient samples are bracketed during analysis by a set of reference standards used to calibrate detector response. CH₄ was isolated from constituent gases through gas chromatography and quantified with flame ionization detection. Measurements are reported in parts per billion (ppb). CO was isolated from constituent gases with gas chromatography and detected by resonance fluorescence at ~150 nm, or by reaction with HgO to produce mercury and detection through Hg resonance absorption, and reported in ppb. H₂ was isolated using gas chromatography, reacted with HgO, and detected through Hg resonance absorption. H₂ quantities are reported in ppb. The N₂O and SF₆ sample components were isolated using gas chromatography and quantified with electron capture detection. N₂O and SF₆ are reported in ppb and parts per trillion (ppt), respectively.

More detailed description of sample analyses is provided at the [NOAA ESRL PFP page](#).

Picarro Instruments

Picarro CRDS instruments were flown aboard both the C-130 and B-200. 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 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 CO₂ and 2 ppb for CH₄ (Karion et al., 2013) also exceed mission accuracy requirements of 1 ppm for CO₂ and 4 ppb for CH₄.

2B Technologies Continuous O₃

The Model 205 O₃ monitor uses two ultraviolet beams in two cells to simultaneously measure O₃-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 O₃ monitor available. The O₃ 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).

CAMS-2

The Compact Atmospheric Multi-Species Spectrometer (CAMS-2) instrument was flown aboard the B-200 aircraft (Richter et al. 2017). CAMS-2 is a compact, laser-based mid-IR absorption spectrometer and performs continuous airborne sampling for CO₂, CH₄, and Ethane (C₂H₆). For ACT-America, the CAMS-2 instrument measured ethane at 1-second intervals with a detection sensitivity of ~30 to 62 pptv. Ethane measurements from the CAMS-2 instrument are included in data files for B-200 flights only.

Merged Data Products

Three merged data products were generated from source measurements and samples acquired during flights over the central and eastern United States between August 2016 and March 2017. Two 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.

- The 1- and 5-second merge products are composed of
 - (1) continuous in situ instrument measurements of atmospheric carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), ozone (O₃), and ethane (C₂H₆, B200 aircraft only)
 - (2) the results of the analyses of ~50 CO₂, CO, molecular hydrogen (H₂), halocarbons, hydrocarbons and sulfur containing trace gases in discrete flask samples collected with the Programmable Flask Package (PFP)
 - (3) the aircraft navigation and meteorological variables.
- The discrete flask-based merge product is composed of
 - (1) the results of the analyses of the discrete PFP flask samples (~50 CO₂, CO, H₂, halocarbons, hydrocarbons and sulfur

- containing trace gases)
 - (2) the continuous in situ instrument measurements of atmospheric CO₂, CH₄, CO, O₃, and C₂H₆ (B200 aircraft only) averaged for the 15-second period surrounding each flask sample's timestamp
 - (3) the aircraft navigation and meteorological variables averaged to the individual flask sample's collection time.

The methods used to combine the data points for each time interval are described in Section 3 of the documentation for the [Toolsets for Airborne Data](#) (NASA ASDC), also included as a companion file (*TAD-Documentation.pdf*).

6. Data Access

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

[ACT-America: L3 Merged In Situ Atmospheric Trace Gases and Flask Data, 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 1.2 (released 2020-06-10) updated data files for the first 4 campaigns and added data files for the 2019 summer campaign.

Version 1.1 (released 2019-02-25) updated all merge data from Summer 2016 and Winter 2017 campaigns to fully science quality data. Data from the Fall 2017 and Spring 2018 campaign were also released.

Version 1.0 (released 2018-06-25) provided the merge data from Summer 2016 and Winter 2017 campaigns, including some data flagged as preliminary (filename contains "RD").



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