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# CARAFE: Regional Airborne Greenhouse Gases Eddy Covariance Measurements, 2016-2017

## Get Data

Documentation Revision Date: 2022-01-27

Dataset Version: 1.1

### Summary

This dataset provides airborne eddy covariance (EC) fluxes of carbon dioxide, methane, sensible heat, and latent heat at high spatial resolution collected during the NASA Carbon Airborne Flux Experiment (CARAFE) airborne 2016 and 2017 campaigns. CARAFE utilized the NASA C-23 Sherpa aircraft with a suite of commercial and custom instrumentation. Deployment occurred across the Mid-Atlantic Region for the period 2016-09-07 through 2016-09-26 and 2017-05-03 through 2017-05-26. The data also include downwelling radiation, water vapor, pressure, temperature, wind, and aircraft navigation data. Airborne EC can quantify surface fluxes at local to regional scales, potentially helping to bridge gaps between top-down and bottom-up flux estimates and offering novel insights into biophysical and biogeochemical processes.

There are 139 data files included in this dataset, including 120 files in ICARTT (\*.ict) format and 19 files in \*.rtso format. There are also five companion files, including four files in Portable Document Format (\*.pdf) format and one file in Interactive Data Language (IDL) named program file (\*.pro) format.

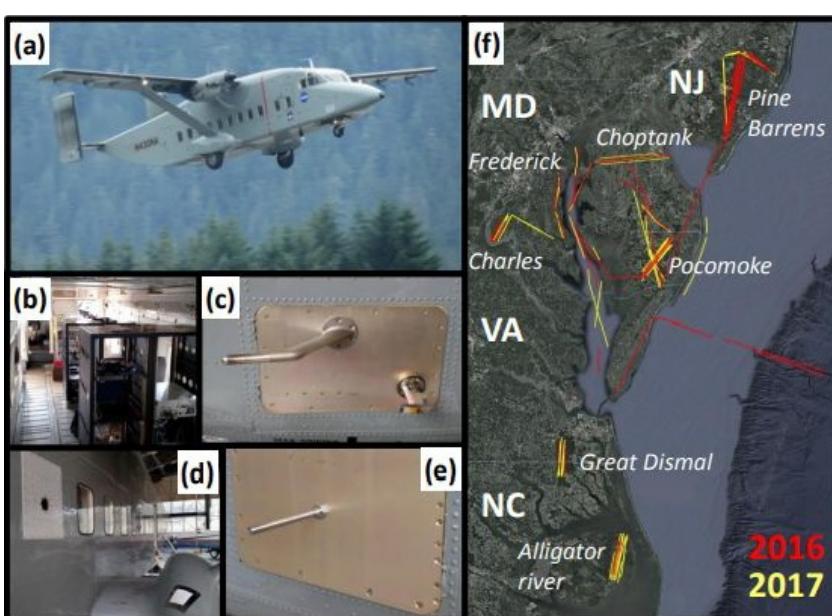


Figure 1. The CARAFE payload. (a) The NASA C-23 Sherpa. (b) A view inside the cabin with all instruments installed. (c) The angle-of-attack (upper) and total air temperature (lower) probes. (d) The DLH window plate (upper left) and fairing-mounted target (lower right). (e) GHG inlet. (f) Flux leg flight tracks for both campaigns.

### Citation

Wolfe, G.M., S.R. Kawa, T.F. Hanisco, R.A. Hannun, P.A. Newman, A.K. Swanson, S.A. Bailey, J.D. Barrick, K.L. Thornhill, G.S. Diskin, J.P. DiGangi, J.B. Nowak, C.E. Sorensen, G.L. Bland, J.K. Yungel, and C.A. Swenson. 2021. CARAFE: Regional Airborne Greenhouse Gases Eddy Covariance Measurements, 2016-2017. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAC/2002>

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# 1. Dataset Overview

This dataset provides airborne eddy covariance (EC) fluxes of carbon dioxide, methane, sensible heat, and latent heat at high spatial resolution collected during the NASA Carbon Airborne Flux Experiment (CARAFE) airborne 2016 and 2017 campaigns. CARAFE utilized the NASA C-23 Sherpa aircraft with a suite of commercial and custom instrumentation. Deployment occurred across the Mid-Atlantic Region for the period 2016-09-07 through 2016-09-26 and 2017-05-03 through 2017-05-26. The data also include downwelling radiation, water vapor, pressure, temperature, wind, and aircraft navigation data. Airborne EC can quantify surface fluxes at local to regional scales, potentially helping to bridge gaps between top-down and bottom-up flux estimates and offering novel insights into biophysical and biogeochemical processes.

## Project: CARbon Airborne Flux Experiment

The NASA CARbon Airborne Flux Experiment (CARAFE) utilized the NASA C-23 Sherpa aircraft with a suite of commercial and custom instrumentation to acquire fluxes of carbon dioxide, methane, sensible heat, and latent heat at high spatial resolution. Continuous wavelet transforms deliver spatially resolved fluxes along aircraft flight tracks. Typical uncertainties in derived surface fluxes are 40–90% for a nominal resolution of 2 km or 16–35% when averaged over a full leg (typically 30–40 km). CARAFE had successfully flown two campaigns in the eastern US in 2016 and 2017, quantifying fluxes over forest, cropland, wetlands, and water.

## Related Datasets

Wolfe, G.M., S.R. Kawa, T.F. Hanisco, R.A. Hannun, P.A. Newman, A.K. Swanson, S.A. Bailey, J.D. Barrick, K.L. Thornhill, G.S. Diskin, J.P. DiGangi, J.B. Nowak, C.E. Sorensen, G.L. Bland, J.K. Yungel, and C.A. Swenson. 2021. CARAFE: Regional Airborne Greenhouse Gases Eddy Covariance Measurements, 2016-2017. ORNL DAAC, Oak Ridge, Tennessee, USA. <https://doi.org/10.3334/ORNLDAAAC/1886>

- Initial release of the dataset, which includes all files available at the NASA LaRC mission page for CARAFE (<https://www-air.larc.nasa.gov/missions/carafe/>). Now superseded by version 1.1 (current dataset) and available only upon request.

## Related Publication

Wolfe, G.M., S.R. Kawa, T.F. Hanisco, R.A. Hannun, P.A. Newman, A. Swanson, S. Bailey, J. Barrick, K.L. Thornhill, G. Diskin, J. DiGangi, J.B. Nowak, C. Sorenson, G. Bland, J.K. Yungel, and C.A. Swenson. 2018. The NASA Carbon Airborne Flux Experiment (CARAFE): instrumentation and methodology. *Atmospheric Measurement Techniques* 11:1757–1776. <https://doi.org/10.5194/amt-11-1757-2018>

## Acknowledgments

The CARAFE 2016 and 2017 missions were supported by NASA Goddard Space Flight Center's Internal Research and Development, the NASA Carbon Monitoring System Program (NNH15ZDA001N-CMS), and the NASA HQ Earth Science Division.

# 2. Data Characteristics

**Spatial Coverage:** Mid-Atlantic U.S.

**Spatial Resolution:** Points

**Temporal Coverage:** 9 days (07, 09, 12, 14, 16, 22, 23, 24, and 26) in September 2016 and 10 days (03, 04, 08, 09, 10, 15, 16, 18, 19, and 26) in May 2017

**Temporal Resolution:** Seconds

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

Site	Northernmost Latitude	Southernmost Latitude	Easternmost Longitude	Westernmost Longitude
Mid-Atlantic U.S.	41.11453923	35.17605461	-73.564453	-79.89257812

## Data File Information

There are 139 data files included in this dataset, including 120 files in ICARTT (\*.ict) format and 19 files in \*.rtso format. There are also five companion files, including four files in Portable Document Format (\*.pdf) format and one file in IDL named program file (\*.pro) format.

Generally, the data files are named CARAFE-<dataID>\_SHERPA\_<date>\_<revision>\_<launch>\_<comments>.<extension>, where

- <dataID> = short description of measured parameter/species, instrument, or model preceded by the mission name "CARAFE-" (DLH, FLUX, GHG-1Hz, GHG-10Hz, MET, or WINDS)
- <locationID> = short description of site, station, platform, laboratory, or institute (SHERPA or SONDES)
- <date> = four-digit year (2016 or 2017), two-digit month (05 or 09), two-digit day; the date always refers to the UTC date of launch
- <revision> = revision number of data (e.g., R0, R1)
- <launch> = optional launch number (L1, L2)
- <comments> = optional additional information (10Hz, or 20Hz)
- <extension> = file extension (\*.ict or \*.rtso)

Table 1. File names and descriptions.

File Names	Number of Files	Description
<b>Data Files</b>		
CARAFE-DLH_SHERPA_<date>_<revision>_<launch>_<comments>.ict	40	Water vapor mixing ratio and relative humidity data collected with a Diode Laser Hygrometer (DLH). There are two files for each date, one sampled at 1 Hz and another sampled at 20 Hz (includes "20Hz" in the filename).
CARAFE-FLUX_SHERPA_<date>_<revision>_<launch>.ict	20	CO <sub>2</sub> flux, CH <sub>4</sub> flux, and flux error data.
CARAFE-GHG-1Hz_SHERPA_<date>_<revision>_<launch>.ict	20	Greenhouse gas suite including CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O dry mole fractions sampled at 1 Hz.
CARAFE-GHG-10Hz_SHERPA_<date>_<revision>_<launch>.ict	20	Greenhouse gas suite including CO <sub>2</sub> , CH <sub>4</sub> , H <sub>2</sub> O dry mole fractions sampled at 10 Hz.
CARAFE-MET SONDES_<date>_R0.rtso	19	Raw radiosonde data. There is one file for each of the dates for 2016 (9 files) and 2017 (10 files). The companion file IDL_reader_for_sondes_rtso_files.pro is provided for data access using

		IDL software. These files can also be opened in generic text software.
CARAFE-WINDS_SHERPA_<date>_<revision>_<launch>.ict	20	Fast, in-situ 3-D wind data. Note that the WINDS data files also contain important navigational and environmental variables, including aircraft position (latitude, longitude, and altitude), aircraft attitude (pitch, roll, and heading), speed, static pressure, and temperature.
<b>Companion Files</b>		
CARAFE_2016_2017_v1.1_variables.pdf	1	Variable names and descriptions for all data files.
CARAFE_Flight_Reports_2016.pdf	1	Flight details for the 2016 campaign.
CARAFE_Flight_Reports_2017.pdf	1	Flight details for the 2017 campaign.
IDL_reader_for_sondes_rtso_files.pro	1	An Interactive Data Language (IDL) file for visualization of the sondes data.

#### Data File Details

The Coordinate Reference System is "WGS 84" (EPSG:4326).

Variable names and descriptions for all data files are available in the companion file CARAFE\_2016\_2017\_v1.1\_variables.pdf.

### 3. Application and Derivation

Measurements acquired from this mission were designed to help answer several science questions:

- How does land-air exchange of CO<sub>2</sub> and CH<sub>4</sub> respond to climate-induced stresses (e.g., heat, drought, pests)?
- How do energy production (e.g., oil/gas, corn ethanol) and agricultural activities impact greenhouse gas inventories?

These data could be useful to climate change studies (Hannun et al., 2020). The exchange of trace gases between the Earth's surface and atmosphere strongly influences atmospheric composition. Airborne eddy covariance (EC) can quantify surface fluxes at local to regional scales (1–1000 km), potentially helping to bridge gaps between top-down and bottom-up flux estimates and offering novel insights into biophysical and biogeochemical processes.

### 4. Quality Assessment

All uncertainties are provided as explicit variables or in the headers and are reported for each sampling interval. Uncertainty in EC fluxes arises from measurement limitations, sampling strategies, and the fundamental nature of turbulence. When extrapolating airborne fluxes to the surface, uncertainties in vertical flux divergence must also be considered. Fluxes of CH<sub>4</sub> were negligibly small for most of the mission, thus the fractional errors are biased high. When flying over methane source regions (e.g., wetlands), CH<sub>4</sub> flux errors are comparable to those in CO<sub>2</sub> flux.

The quality of the 3-D wind measurement hinges on the performance of the differential pressure measurements. Uncertainty information is also provided as notes in the companion file CARAFE\_Fall\_2016\_2017\_v1.1\_variables.pdf.

Water vapor data are averaged to 20 Hz with a typical precision ( $1\sigma$ ) of 0.3% or better. Overall measurement accuracy was within 5%, based on field inter-comparisons on other airborne platforms (Jensen et al., 2017; Rollins et al., 2014).

Table 2. Instrument specifications for the CARAFE payload. Source: Wolfe et al. (2018)

Measurement	Instrument	Data rate (Hz)	1 s precision (@ 1 Hz)	Accuracy
CO <sub>2</sub>	LGR	10	330 ppb	600 ppb <sup>a</sup>
	Picarro	0.2	50 ppb	200 ppb <sup>b</sup>
CH <sub>4</sub>	LGR	10	2.0 ppb	4 ppb <sup>a</sup>
	Picarro	0.2	0.4 ppb	1 ppb <sup>b</sup>
H <sub>2</sub> O	LGR	10	200 ppm	7 % <sup>c</sup>
	Picarro	0.07	100 ppm	7 % <sup>c</sup>
	DLH	20	10 ppm	5 %
3-D winds Pressure	TAMMS	20	0.05 m s <sup>-1</sup>	5 %
			0.003 mb	5 %
Vertical wind	Rosemount 858	20	0.05 m s <sup>-1</sup>	5 %
Temperature	Rosemount TAT	20	0.05 K	5 %
Aircraft position	Applanix 510	20	–	100 m
Aircraft attitude			–	0.005°
Telemetry	NASDAT	20	–	–
Visible imagery	Nikon D7000			
IR imagery	FLIR 325sc	1	–	–
Four-band veg. health	MS RedEdge			
PPFD	LI-190R	1	–	10 %

<sup>a</sup> Based on Picarro accuracy and variance of LGR–Picarro difference in 1 Hz observations. <sup>b</sup> Based on laboratory calibrations and in-flight performance of similar instruments (Chen et al., 2010; Karion et al., 2013b). <sup>c</sup> Based on in-flight comparison with DLH.

## 5. Data Acquisition, Materials, and Methods

### Overview

The NASA CARAFE mission utilized the NASA C-23 Sherpa aircraft with a suite of commercial and custom instrumentation to acquire fluxes of carbon dioxide, methane, sensible heat, and latent heat at high spatial resolution. Key components of the CARAFE payload (Table 2) include meteorological, greenhouse gas, water vapor, and surface imaging systems. Continuous wavelet transforms delivered spatially resolved fluxes along aircraft flight tracks.

Deployment occurred across the Mid-Atlantic Region for the period 2016-09-07 through 2016-09-26 and 2017-05-03 through 2017-05-26 (Table 3). In particular, flights occurred over the Pocomoke Forest area on the Eastern Shore of Maryland; agricultural areas and tidal marshlands from the Eastern Shore of Virginia to southern Delaware; southern Maryland; the Chesapeake Bay and the Atlantic Ocean; the New Jersey Pine Barrens in the southern portion of the state; and the Alligator River and the Great Dismal Swamp in eastern North Carolina and southeastern Virginia.

Table 3. Dates and locations of CARAFE deployments

Flight #	Flight Date	Flight Time (EDT)	Destination	Flux Legs	Tower Overpass <sup>a</sup>
1	7 Sep 2016	12:25 - 15:59	Pocomoke Forest (MD)	6	
2	9 Sep 2016	11:23 - 15:20	Pocomoke Forest (MD)	13	
3	12 Sep 2016	11:06 - 15:03	Choptank Ag (MD/DE)	9	USDA-Chop, US-StJ
4	14 Sep 2016	11:07 - 15:17	Pine Barrens (NJ)	12	US-Slt, US-Ced
5	16 Sep 2016	11:21 - 15:10	Pocomoke Forest (MD)	15	
6	22 Sep 2016	11:58 - 16:00	Prince Frederick (MD) Charles County (MD)	6 8	
7	23 Sep 2016	11:12 - 15:05	Pine Barrens (NJ)	12	US-Slt, US-Ced
8	24 Sep 2016	10:47 - 14:35	Great Dismal (VA/NC) Alligator River (NC) Atlantic Ocean	7 6 4	US-NC4
9	26 Sep 2016	11:04 - 15:10	Chesapeake Bay Pocomoke Forest (MD)	5 2	
1	3 May 2017	15:00 - 17:27	Pocomoke Forest (MD)	4	
2	4 May 2017	11:12 - 15:03	Choptank Ag (MD/DE) Pocomoke Forest (MD)	7 3	USDA-Chop, US-StJ
3	8 May 2017	10:42 - 12:23	Pocomoke Forest (MD)	7	
4	8 May 2017	14:02 - 17:40	Pocomoke Forest (MD)	16	
5	9 May 2017	11:01 - 15:05	Pine Barrens (NJ)	16	US-Slt, US-Ced
6	10 May 2017	11:56 - 14:32	Prince Frederick (MD) Charles County (MD)	7 8	
7	15 May 2017	12:59 - 15:49	Alligator River (NC)	6	US-NC4
8	16 May 2017	11:08 - 15:02	Great Dismal (VA/NC) Chesapeake Bay	4 6	
9	18 May 2017	11:05 - 15:05	Choptank Ag (MD/DE)	10	USDA-Chop, US-StJ
10	19 May 2017	10:04 - 13:29	Pocomoke Forest (MD)	13	
11	26 May 2017	08:51 - 12:55	Alligator River (NC)	11	US-NC4

<sup>a</sup>Abbreviations: USDA-Chop = Choptank, MD; US-StJ = St. Jones Preserve, DE; US-Slt = Silas Little, NJ; US-Ced = Cedar Bridge, NJ; US-NC4 = Alligator River, NC. More information on towers available at the [ameriflux.lbl.gov/](http://ameriflux.lbl.gov/) and <https://www.ars.usda.gov/northeast-area/beltsville-md/beltsville-agricultural-research-center/hydrology-and-remote-sensing-laboratory/docs/research-sites/>.

The scientific objectives of CARAFE were to:

- Observe and quantify fluxes of carbon dioxide, methane, sensible heat, and latent heat at a high spatial resolution over a spectrum of ecosystems,
- Assemble a versatile, economical system for measuring airborne fluxes,
- Evaluate biophysical process models and parameterizations, and
- Validate satellite flux products from OCO-2 and other missions.

### Meteorology & Telemetry

Meteorology and telemetry measurements were made using the Sherpa Turbulent Air Motion and Meteorology System (TAMMS), a suite of sensors for high-frequency measurement of horizontal and vertical wind vectors, pressure, and temperature. Winds were derived from five pitot static-pressure ports mounted on the radome (nose) of the aircraft (Brown et al., 1983; Thorntill et al., 2003). In essence, these sensors provide the velocity of air with respect to the aircraft. Combining this information with a high-quality GPS and Inertial Navigation System (Applanix 510) yielded the velocity of air with respect to the Earth's surface. A hatch on the forward left side supported a Rosemount model 858 angle-of-attack probe for redundant vertical wind measurements and a Rosemount model 102 non-deiced total air temperature sensor housing coupled with a platinum sensing element (E102E4AL;

### Water Vapor

The NASA Langley Diode Laser Hygrometer (DLH; Diskin et al., 2002), is an open-path infrared absorption spectrometer that uses a variation of wavelength modulation spectroscopy (Silver, 1992) to measure water vapor mole fraction. Data were processed at the instrument's native 100 Hz acquisition rate.

### Greenhouse Gas Suite

The greenhouse gas (GHG) suite consisted of several modified commercial analyzers coupled with custom hardware for fast gas flow and centralized data acquisition. Two Los Gatos Research (LGR) analyzers, one for CO<sub>2</sub> (model no. 907-0020-1000) and the other for CH<sub>4</sub> and water vapor (model no. 913-0014-0001), acquired mixing ratios at 10 Hz. A Picarro G1301-m analyzer supplies an additional set of CO<sub>2</sub>/CH<sub>4</sub>/H<sub>2</sub>O mixing ratios. Compared to the LGR analyzers, the Picarro provided reduced-duty precision and stability. Thus, the LGR systems provided fast measurements needed for EC flux calculations while the Picarro served as an accuracy standard. For the 2016 deployment, a Picarro G2401-m replaced the G1301-m for the last four flights following a power supply failure on the latter. Data streams from all analyzers, along with a GPS feed, were recorded via RS232 using a National Instruments Compact RIO controller.

Refer to Wolfe et al. (2018) for additional information.

## 6. Data Access

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

[CARAFE: Regional Airborne Greenhouse Gases Eddy Covariance Measurements, 2016-2017](#)

Contact for Data Center Access Information:

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

## 7. References

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## 8. Dataset Revisions

Version	Release Date	Revision Notes
1.1	2021-01-28	Excludes data that were considered preliminary (i.e., revision number "RA" or "RB"): CO-N2O, VWINDS, Hskping, mrg01-SHERPA, and mrg60-SHERPA. Other data remain the same as in Version 1.0.
1.0	2021-09-20	Initial release of the dataset. Includes all files available at the NASA LaRC mission page for CARAFE ( <a href="https://www-air.larc.nasa.gov/missions/carafe/">https://www-air.larc.nasa.gov/missions/carafe/</a> ). Superseded by Version 1.1 and available only upon request.

Mission	Science Themes	Submit Data Form	MODIS	Learning
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Partners		Data Publication Timeline	Airborne Data Visualizer	
		Detailed Submission	Soil Moisture Visualizer	
		Guidelines	Land - Water Checker	