BlueFlux Airborne Trace Gases, Fluxes, and Mixing Ratios, Southern Florida, 2022-2023

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Documentation Revision Date: 2024-03-22

Dataset Version: 1

Summary

This dataset includes airborne in situ measurements of greenhouse gas mixing ratios, meteorological parameters, and fluxes (CO2, CH4, latent heat fluxes, friction velocity, and convective velocity scale) calculated with wavelet transforms. CO2, CH4, CO, O3, and water vapor mixing ratios, and meteorological variables were obtained from a Beechcraft A90 King Air aircraft. Flights occurred on April 19-26 2022, October 14-20 2022, February 5-13 2023, and April 13-19 2023 as part of the BlueFlux campaign, funded by NASA's Carbon Monitoring System program. Measurements were made with several instruments, including a PICARRO 2401-m (0.5 Hz CO2/CH4/H2O/CO), PICARRO 2311-f (10 Hz CO2/CH4/H2O), NASA Rapid Ozone Experiment (ROZE, 10 Hz O3), and AIMMS-20 probe (3-D winds, meteorology, and aircraft location data). Flight lines span Everglades National Park (ENP) and Big Cypress National Preserve (BCNP) in southern Florida, USA. The measurements were used to calculate vertical fluxes of trace gases and heat via wavelet transform eddy covariance

There are 159 data files in ICARTT (.ict) version 1.1 format with this dataset.

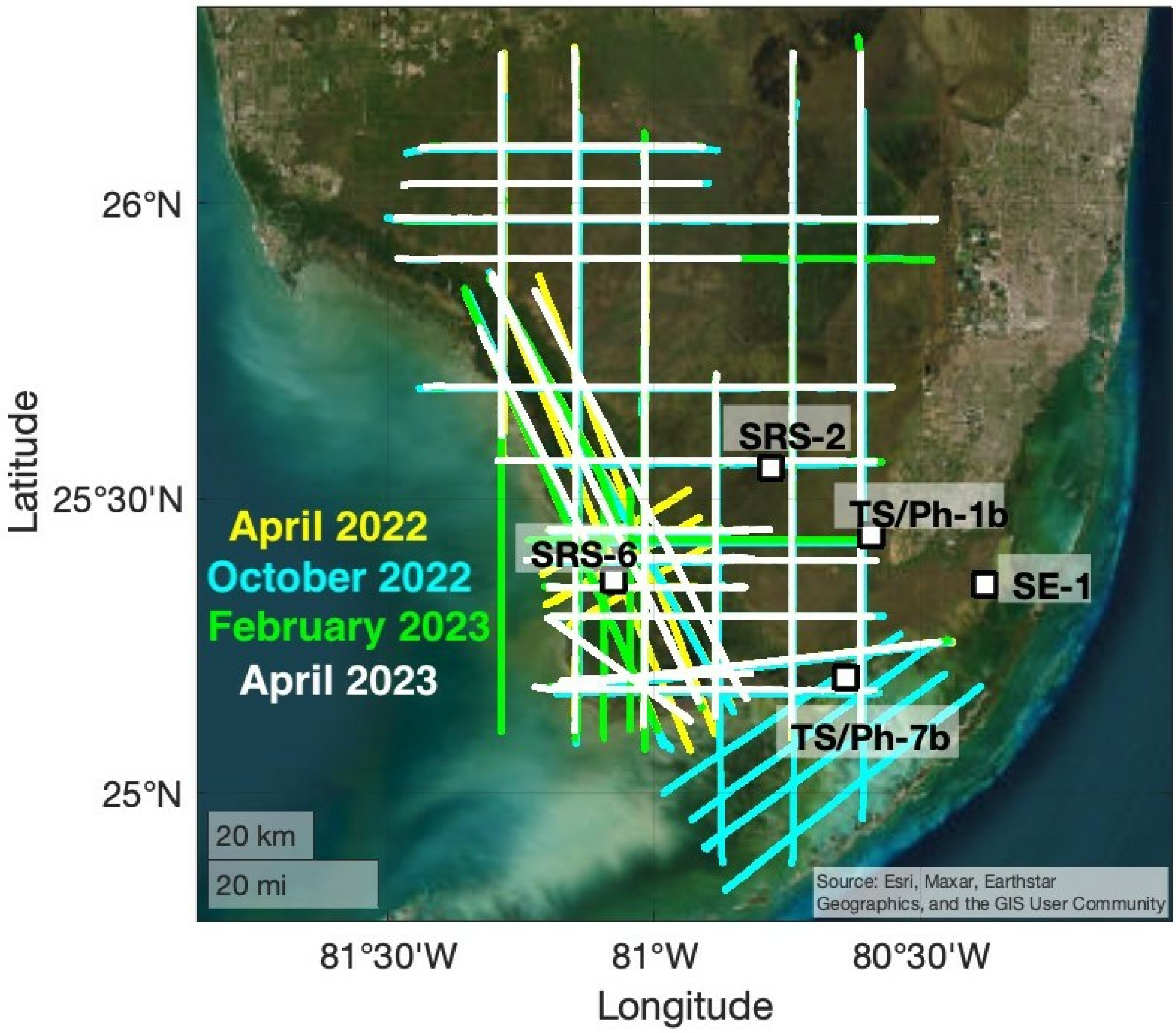

Figure 1. Map of flight lines for each deployment during the campaign. The squares are ground-based tower measurements. Map courtesy of E.R. Delaria.

Citation

Delaria, E.R., G.M. Wolfe, R.A. Hannun, K. Blanock, B. Poulter, and K.L. Thornhill. 2024. BlueFlux Airborne Trace Gases, Fluxes, and Mixing Ratios, Southern Florida, 2022-2023. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/2327

Table of Contents

1. Dataset Overview

This dataset includes airborne in situ measurements of greenhouse gas mixing ratios, meteorological parameters, and fluxes (CO_2, CH_4, latent heat fluxes, friction velocity, and convective velocity scale) calculated with wavelet transforms. CO_2, CH_4, CO, O_3, and water vapor mixing ratios, and meteorological variables were obtained from a Beechcraft A90 King Air aircraft. Flights occurred on April 19-26 2022, October 14-20 2022, February 5-13 2023, and April 13-19 2023 as part of the BlueFlux campaign, funded by NASA's Carbon Monitoring System program. Measurements were made with several instruments, including a PICARRO 2401-m (0.5 Hz CO_2/CH_4/H_2O/CO), PICARRO 2311-f (10 Hz CO_2/CH_4/H_2O), NASA Rapid Ozone Experiment (ROZE, 10 Hz O_3), and AIMMS-20 probe (3-D winds, meteorology, and aircraft location data). Flight lines span Everglades National Park (ENP) and Big Cypress National Preserve (BCNP) in southern Florida, USA. The measurements were used to calculate vertical fluxes of trace gases and heat via wavelet transform eddy covariance

Project: Carbon Monitoring System

The NASA Carbon Monitoring System (CMS) program is designed to make significant contributions in characterizing, quantifying, understanding, and predicting the evolution of global carbon sources and sinks through improved monitoring of carbon stocks and fluxes. The System uses NASA satellite observations and modeling/analysis capabilities to establish the accuracy, quantitative uncertainties, and utility of products for supporting national and international policy, regulatory, and management activities. CMS data products are designed to inform near-term policy development and planning.

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, and J. DiGangi. 2018; The NASA carbon airborne flux experiment (CARAFE): instrumentation and methodology. Atmospheric Measurement Techniques 11:1757-76. https://doi.org/10.5194/amt-11-1757-2018

Acknowledgments

This study was funded by the NASA Carbon Monitoring System (WBS 281945.02.03.11.35) and the NASA Postdoctoral Program.

2. Data Characteristics

Spatial Coverage: southern Florida, USA

Spatial Resolution: approximately 7-8 m for 10-Hz measurements; 70-80 m for 1-Hz data; and 150 m for 0.5-Hz data.

Temporal Coverage: Four deployment periods. April 19-26 2022, October 14-20 2022, February 5-13 2023, and April 13-19 2023

Temporal Resolution: 10 Hz for fast GHG and O_3 mixing ratios. 0.5 Hz data for slow GHG mixing ratios. 1 Hz for flux data. 20 Hz for meteorological data.

Study Area: Latitude and longitude are given in decimal degrees

Site	Westernmost Longitude	Easternmost Longitude	Northernmost Latitude	Southernmost Latitude
southern Florida	-81.53	-80.35	29.99	24.80

Data File Information

There are 159 data files in ICARTT (.ict) version 1.1 format with this dataset.

Files are named in accordance with the ICARTT naming convention:
<project>-<measurement>_<platform>_<date>_<revision number>_<sortie>.ict, where

- *<project>* = "blueflux"
- *<measurement>* = measurement type listed in Table 1
- *<platform>* = "kingair"
- *<revision number>* = data processing revision number (e.g., "R0", "R1", "R2"), etc.
- *<sortie>* = optional flight leg or sortie designator (e.g., "L1, "L2")

Table 1. Measurement types.

Measurement	Description (instrument)
ghg-slow	0.5 Hz CO_2/CH_4/H_2O/CO mixing ratios (PICARRO 2401-m)

ghg-fast	10 Hz CO_2/CH_4/H_2O mixing ratios (PICARRO 2311-f)
roze	ozone (O_3) mixing ratios (NASA Rapid OZone Experiment, ROZE)
ghg-flux	fluxes of greenhouse gases and meteorological parameters
o3-flux	fluxes of ozone and meteorological parameters
aimms20	winds and meteorological measurements (Aircraft-Integrated Meteorological Measurement System, AIMMS-20)
metmodel	high resolution rapid refresh meteorological model interpolated along the flight track

Ozone flux and concentration measurements are only available for the deployment periods February 2023 and April 2023.

Data File Properties:

These files are ICARTT time-series data files in text format. The ICARTT version 1.1 format specification is available at https://www-air.larc.nasa.gov/missions/etc/IcarttDataFormat.htm. The files contain columns of variables at different time points along the flight line, indicated by the time variable in each file given in UTC in units of seconds. Each ICARTT file includes a header holding metadata with details that may be specific to the data contained therein.

Missing data are typically indicated by -9999 or -99999; see metadata in file header.

Table 1. Variables in the data files.

Variable	Units	Description	Measurement type
Time_Start	s	Start time of measurement	ghg-slow,ghg-fast
Time_Stop	s	Stop time of measurement	ghg-slow
Time_Mid	s	Midpoint of measurement	ghg-flux, o3-flux,metmodel
UTC_mid	s	Seconds after midnight, Time of acquisition	aimms20
CO2_ppm	ppm	Dry mole fraction of carbon dioxide	ghg-slow, ghg-fast
CH4_ppm	ppm	Dry mole fraction of methane	ghg-slow, ghg-fast
H2O_ppm	ppm	Mixing ratio of water vapor	ghg-slow, ghg-fast
CO_ppb	ppb	Mixing ratio of carbon monoxide	ghg-slow
GPS_Alt	m	Garmin GPS altitude	ghg-slow, ghg-fast
GPS_Lon	deg	Garmin GPS longitude	ghg-slow, ghg-fast
GPS_Lat	deg	Garmin GPS latitude	ghg-slow, bghg-fast
Leg	-	Flight leg (sortie) index	ghg-flux, o3-flux
Lat	degrees_north	GPS latitude	ghg-flux, o3-flux, metmodel
Lon	degrees_east	GPS longitude	ghg-flux, o3-flux, metmodel
Alt	m	GPS altitude	ghg-flux, o3-flux
Dist	m	Distance along leg	ghg-flux, o3-flux
ustar	$m\ s^{-1}$	Friction velocity	ghg-flux, o3-flux
wstar	$m\ s^{-1}$	Convective velocity scale	ghg-flux, o3-flux
LE	$W\ m^{-2}$	Latent heat flux	ghg-flux
FCO2	$umol\ m^{-2}\ s^{-1}$	CO_2 flux	ghg-flux
FCH4	$nmol\ m^{-2}\ s^{-1}$	CH_4 flux	ghg-flux
LE_RE	$W\ m^{-2}$	flux random error for latent heat	ghg-flux
FCO2_RE	$uumol\ m^{-2}\ s^{-1}$	flux random error for CO_2	ghg-flux
FCH4_RE	$nmol\ m^{-2}\ s^{-1}$	flux random error for CH_4	ghg-flux
LE_SE	-	flux systematic error fraction	ghg-flux
FCO2_SE	-	flux systematic error fraction for CO_2	ghg-flux
FCH4_SE	-	flux systematic error fraction for CH_4	ghg-flux
LE_qflag	-	LE quality flag	ghg-flux

FCO2_qflag	-	FCO2 quality flag	ghg-flux
FCH4_qflag	-	FCH4 quality flag	ghg-flux
u	m s^{-1}	Along-vector wind speed	ghg-flux, o3-flux
v	m s^{-1}	Cross-vector horizontal wind speed	ghg-flux, o3-flux
WDIR	deg	Calculated horizontal wind direction	ghg-flux, o3-flux
WSPD	deg	Calculated horizontal wind direction	ghg-flux, o3-flux
u_std	m s^{-1}	Standard deviation of along-vector wind speed	bghg-flux, o3-flux
v_std	m s^{-1}	Standard deviation of cross-vector horizontal wind speed	ghg-flux, o3-flux
w_std	m s^{-1}	Standard deviation of vertical wind speed	ghg-flux, o3-flux
Lobukhov	m	Obukhov length	ghg-flux, o3-flux
FO3	nmol m-2 s-1	O_3 flux	o3-flux
FO3_RE	nmol m-2 s-1	O_3 flux random error	o3-flux
FO3_SE	-	O_3 flux systematic error fraction	bo3-flux
FO3_qflag	-	FO3 quality flag	o3-flux
Latitude_deg	degrees_north	Latitude from AIMMS-20	aimms20
Longitude_deg	degrees_east	Longitude form AIMMS-20	aimms20
gpsALT_ft	ft	GPS altitude from AIMMS-20 in feet	aimms20
u_ms-1	m s^{-1}	East/west wind	aimms20
v_ms-1	m s^{-1}	North/south wind	aimms20
w_ms-1	m s^{-1}	Vertical wind	aimms20
WSPD_ms-1	m s^{-1}	Horizontal wind speed	aimms20
WDIR_deg	degrees	Horizontal wind direction	aimms20
Tstat_degC	degrees_C	Static air temperature	aimms20
RH	percent	Relative humidity	aimms20
Pstat_mb	Mb	Static pressure	aimms20
Pitch_deg	degrees	Aircraft pitch angle	aimms20
Roll_deg	degrees	Aircraft roll angle	aimms20
HDG_deg	degrees	Aircraft heading	aimms20
TAS_ms-1	m s^{-1}	Aircraft true air speed	aimms20
HPBL	m	Mixed layer depth	metmodel

3. Application and Derivation

BlueFlux is a NASA Carbon Monitoring Systems (CMS) project to measure greenhouse gases (GHG) in Florida mangrove and related ecosystems. Airborne flux measurements were performed in southern Florida over the Everglades and Big Cypress National Preserve region during April 2022, October 2022, February 2023, and April 2023. Flux transects during each deployment are linear flight portions of length 30 -150 km at an altitude of ~300 ft (90 m) and average airspeed of 65 - 80 m s^{-1} (130 - 150 kts). Flights were designed to have flux legs greater than 20 km in length targeting mangrove forests, regions of recent mangrove dieback (ghost forests), and areas with different dominant vegetation. The dataset includes continuous in situ measurements of CO_2, CH_4, CO, H_2O, and derived fluxes of CO_2, CH_4, O_3, sensible heat (H) and latent heat (LE). This dataset covers a large section of the southern Florida region and demonstrates the heterogeneity of GHG and O_3 exchange.

4. Quality Assessment

Measurements of the mixing ratios in “blueflux-ghg-slow” made with the PICARRO 2401-m have an accuracy (systematic uncertainty) of 0.2 ppm CO_2, 0.004 ppm CH_4, 1.3 ppb CO, and 2 ppm H_2O. Precision (random uncertainty) is 0.03 ppm CO_2, 0.0002 ppm CH_4, 3 ppb CO, and 20 ppm H_2O.

Mixing ratios provided in “blueflux-ghg-fast”, measured with the PICARRO 2311-f have an accuracy (systematic uncertainty) of +/- 0.2 ppm, +/- 0.004 ppm, and +/- 200 ppm for CO_2, CH_4, and H_2O, respectively. Precision (random uncertainty) is 0.08 ppm CO_2, 0.0006 ppm CH_4, and 1 ppm + 3% for H_2O.

Uncertainty in the PICARRO measurements were determined from a lab calibration against WMO-traceable standards. When averaging, precision reduces as (number of points)$^{0.5}$, but accuracy does not reduce.

O_3 mixing ratios measured with the ROZE instrument and reported in "blueflux-roze" are accurate to within 6.8% (1 sigma). The accuracy of horizontal winds (u and v) is +/- 0.75 m/s and vertical winds (w) is +/-0.5 m/s.

Uncertainties for derived fluxes are reported in "blueflux-ghg-flux" and "blueflux-o3-flux". Systematic error contributions to flux uncertainties include error due to under-sampling high and low frequencies (SE_{turb}), the instrument response time limiting detection of high-frequency signals (SE_{RT}), and instrument accuracy (SE_{acc}). The e-folding response time used to calculate SE_{RT} was determined through laboratory tests to be 90 ± 10 ms for the PICARRO 2311-f, which translates to an effective cutoff measurement frequency of 3.8 Hz. SE_{acc} for each scalar is based on the measurement precision and that of the vertical wind speed, w. The AIMMS-20 probe has an instrument precision of 10% for the vertical wind. The cumulative systematic error is provided, while component error contributions are available upon request.

Random flux errors are due to turbulence (stochastic noise) and instrument noise. We empirically calculate the total random flux error (RE_{RMSE}) as the root mean squared deviation from zero of the cross-covariance between a scalar, *s,* and *w:*

$$RE_{RMSE} = \sqrt{N}\sqrt{\left(0.5\left(\left(\sigma_{w's'[-\Gamma]}\right)^2 + \left(\overline{f_{w's'[-\Gamma]}}\right)^2 + \left(\sigma_{f_{w's'[+\Gamma]}}\right)^2 + \left(\overline{f_{w's'[+\Gamma]}}\right)\right)\right)^2}$$

Here N is the number of data points per second, $\sigma_{w's'}$ is the standard deviation and $f_{w's'}$ is the average cross-covariance over a time lag range of $-\Gamma$ or $+\Gamma$. The value Γ was defined to be over a time lag range from one to 100 data points. Here 100 was chosen as the maximum lag considered for Γ to be representative of the integral time scale. This representation considered the variability in the cross-covariance of *s* and *w*, as well as the offset from zero related to trends in the data not related to turbulence. Note that RE is given in flux units, while SE is in fractional units.

The total flux error can be calculated as E = sqrt(RE^2 + $(SE*F)^2$). When averaging fluxes, average errors are: SE_{avg} = mean(SE), RE_{avg} = sqrt(sum(RE^2))/N, where N is number of points in the average. Divergence uncertainty should be added in fractional quadrature with RE and SE: E_{surf} = F_{surf}*sqrt(F_div_err^2 + $(RE/F)^2$ + SE^2). Fluxes can become spurious at the beginning/end of a flight leg due to the cone-of-influence. Quality flags (F_qflag) are provided to filter out suspect fluxes. A qflag of 1 denotes good quality fluxes. By definition, F_qflag is 1 when the fraction of cospectral power within the cone-of-influence is < 0.5.

5. Data Acquisition, Materials, and Methods

The data were obtained from in situ measurements from a Beechcraft A90 King Air (N87Q), operated out of Homestead, Florida, USA by Dynamic Aviation during four deployment periods:

- April 2022: 19, 20, 21, 22, 24, 25, and 26
- October 2022: 14, 15, 17, 18, and 20
- February 2023: 6, 7, 8, 10, 11, and 13
- April 2023: 13, 14, 15, 16, 18, and 19

Measurements were made with PICARRO 2401-m (0.5 Hz $CO_2/CH_4/H_2O/CO$), PICARRO 2311-f (10 Hz $CO_2/CH_4/H_2O$), NASA Rapid Ozone Experiment (ROZE, 10 Hz O_3), and AIMMS-20 probe (3-D winds, meteorology, and aircraft location data). Flight data covers much of the southern Florida regions, especially over the Everglades National Park and Big Cypress National Preserve.

Ambient air was sampled from a common inlet (0.5-inch stainless steel with fluoropel coating) located under right wing. The sample tube had an inner diameter 0.25 inch and a length of about 25 feet, material FEP. Each PICARRO instrument was backed by an Agilent IDP3 scroll pump. Both PICARRO instruments were calibrated with WMO-grade calibration NOAA cylinders (IDs CC746186 and CA03516). Greenhouse gas (GHG) instruments were time-aligned through lag correlation. The time response of PICARRO 2311-f was 100 ms (1/e) based on laboratory pulse-decay experiments. 10 Hz PICARRO 2311-f CO_2 and CH_4 data were corrected for a pressure dependence using 2401-m measurements.

The AIMMS-20 probe (Advantech) was mounted under the left wing and measured ambient temperature, pressure, and relative humidity. 3-D winds were calculated from differential dynamic pressures using AIMMS software. Probe calibration flights occurred prior to the start of each deployment.

O_3, CO_2, CH_4, latent heat (LE), sensible heat (H), and momentum fluxes at aircraft radar altitudes of 300-900 ft were calculated with wavelet transforms (Torrence and Compo, 1998) applied to 10-Hz observations over each leg. Scalar time series were detrended with a 40 second (~3 km) running mean. Reported fluxes include contributions from all frequencies, including those within the cone-of-influence. Raw 10-Hz fluxes are bin-averaged to 1 Hz (~70-80 m horizontal resolution). Friction velocities (ustar) are filtered for momentum fluxes with the fraction of the cospectral power lying within the cone-of-influence <0.5. wstar has been filtered in the same manner with sensible heat fluxes.

Ozone flux and concentration measurements are only available for the deployment periods February 2023 and April 2023.

See Wolfe et al. (2018) for additional details about airborne in situ sampling methods.

6. Data Access

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

BlueFlux Airborne Trace Gases, Fluxes, and Mixing Ratios, Southern Florida, 2022-2023

Contact for Data Center Access Information:

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

7. References

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, and J. DiGangi. 2018;

The NASA carbon airborne flux experiment (CARAFE): instrumentation and methodology. Atmospheric Measurement Techniques 11:1757-76.
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Torrence, C., and G.P. Compo. 1998. A practical guide to wavelet analysis. Bulletin of the American Meteorological Society 79:61-78.
https://doi.org/10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2