ARM TR-048

Carbon Dioxide Flux Measurement Systems (CO_2FLX) Handbook

January 2004

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

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3. Deployment Locations and History

The number and location of the sensors on the SGP 60-m tower has changed over time; the following changes have been made:

September 2000. Initial installation of one system on the southeast boom at 60 m on the Central Facility (CF) tower.

December 2002. First system removed from southeast boom. Systems installed on the 25- and 60-m west booms on the CF tower. Combined eddy covariance system at 4.5-m and supporting 4-m meteorological measurement tower installed near base of 60-m tower.

4. Near-Real-Time Data Plots

See data quicklooks from yesterday at:

- yest60m
- yest25m
- yest4m

5. Data Description and Examples

5.1 Data File Contents

The data are presented in three levels of processing: a1, b1, and b1met. Each level of processing has an accordingly named directory. For more detailed information on processing, please see Data Processing Algorithms section. In summary:

Directory 'a1': sgp30p1flxT1.a1.YYYYMMDD.000000.cdf
First level of processing where raw data are converted to physical units, despiked, lag is corrected, statistics are calculated, etc. "YYYYMMDD" denotes year, month, day of the file. All data are in cdf format.

Directory 'b1': sgp30p1flxT1.b1.YYYYMMDD.000000.cdf
Second level of processing where data are quality checked and corrections applied properly rotated.

Directory 'b1met': sgp30p1flxmetT1.b1.YYYYMMDD.000000.cdf
Third level of processing where other meteorological data are added to the b1 level of processing

5.1.1 Primary Variables and Expected Uncertainty

The CO_2 flux systems measurement systems provide from ½- to 4-hour mean estimates of the fluxes of CO_2, H_2O (latent heat), and sensible heat from a variable area (footprint) of the land surface upwind of the instrument. In rough terms, the extent of the footprint, which depends on the mean wind speed and the degree of turbulent mixing in the atmosphere, varies from 5-100 times the height of the sensors above the land surface. For example, the instrument located at 60 m on the CF tower detect land surface fluxes at distances between approximately 0.3-6 km from the tower depending on meteorological conditions.

The fluxes are computed from the following directly measured data. The sonic anemometer at 10 Hz CO_2 meausres orthogonal components of the wind velocity, u, v, and w (m s^{-1}), and sonic temperature (K), which is approximately equal to virtual temperature. An infrared gas analyzer (IRGA) measures H_2O densities (mmol m^{-3}).

5.1.1.1 Definition of Uncertainty

Uncertainties in the measurements obtained under well-mixed conditions are typically dominated by random noise from atmospheric turbulence and the instrument. The most common source of uncertainy at night is caused by imperfect mixing under low turbulence conditions. A third source of uncertainty is noise caused by airborne material (e.g., rain) that briefly obscures the sound or light path of the sensors. The data processing software is designed to provide diagnostic variables to identify the sources of uncertainty that affect the measurements. See the description of processing algorithms given below.

Under normal operation, the instrument noise limits to flux measurements are as follows:
CO_2 flux: detection limit ~ 0.1 umol/m^2/s, gain uncertainty 1-3%
H_2O flux: detection limit ~ 10 W/m^2/s, gain uncertainty 1-3%
Sensible heat: detection limit ~ 10 W/m^2/s, gain uncertainty 1-3%

5.1.2 Secondary/Underlying Variables

Secondary variables are provided for assessing the state of the atmosphere including: friction velocity and Monin-Obukhov scale length; radiatiative balance and surface reflectivity variables including upward and downward shortwave, longwave, and photosynthetically active radiation; and soil variables including soil temperature and moisture.

5.1.3 Diagnostic Variables

Additional diagnostic variables include the first four statistical moments and spike counts (see below) of wind velocity, CO_2 and H_2O vapor densities, and virtual temperature.

5.1.4 Data Quality Flags

Output files include QC flags as described below:

Raw data Quality Assurance (QA)/QC

Spike count for u,v,w,T, q, c

This is a summary of the QC flags in a1 and b1 files.

******Flags present in _a1_ files:

nspk_unrot_u number of samples out of range u

speed > 40m/s
deviation from mean > 6*(std dev)

nspk_unrot_v number of samples out of range v

speed > 40m/s
deviation from mean > 6*(std dev)

nspk_unrot_w number of samples out of range w

speed > 40m/s
deviation from mean > 6*(std dev)

nspk_t number of samples out of range t

deviation from mean > 5*(std dev)

nspk_q number of samples out of range q

value > 2000 $mmol/m^{-3}$
value < 0 $mmol/m^{-3}$
deviation from mean > 6*(std dev)

nspk_c number of samples out of range c

value > 30 $mmol/m^{-3}$
value < 10 $mmol/m^{-3}$
deviation from mean > 6*(std dev)

Processed Data Checks
******Flag Scheme in b1 level files:

Almost every variable 'x' has a quality control flag named 'qc_x'. In general, the values of QC flags are as follows:

Table 1.

qc value	relevant condition
0	value not suspect
1	value missing
2	value below minimun or above maximum or value is +-infinity
4	one or more dependencies failed; see the “dependency” attribute of variable; if a dependency is a spike count, it fails if it is >100, if a dependency is a variable, it fails when the variable’s qc flag is not equal to 0.
8	value has large variance; see “large variance condition” attribute of variable
16	value suspect because variable has more than 100 spikes; these spikes are counted in a1 level data; see “dependencies” attribute of variable; currently this flag applies to t, q, c.
32	value suspect because of another condition, see “special condition” attribute of variable. Currently only applies to fc_corr, wc_2d, ustar.

For more specific minimum, maximum, and other values, please see the Data Description File.

5.1.5 Dimension Variables

Each variable has dimensions included in the data files.

5.2 Annotated Examples

The variable for CO_2 flux is fc_corr (μmol CO_2 m^{-2} s^{-1}). Typical daytime values are –30 < fc_corr < 10 (μmol CO_2 m^{-2} s^{-1}). The corresponding quality control variable is qc_fc_corr (dimensionless) which normall has a value of zero. Low turbulence at night is identified as occurring when the mean wind speed is less than 2 m s^{-1}.

5.3 User Notes and Known Problems

The instruments have provided high quality data for a large fraction (>80%) of their operating lifetime. Occassional loss of data has occurred due to loss of power communications or instrument malfunction. Also, the operation of some of the auxiallary sensors (particularly the soil measurement instruments) has been optimized over time. All data users are strongly urged to review the quality reports describing intermittent problems and changes to sensors and the data processing, then refer further questions to the instrument mentor.

5.4 Frequently Asked Questions

Where do I get more information?
Contact the instrument mentor at mlfischer@lbl.gov.

6. Data Quality

6.1 Data Quality Health and Status

Data quality is evaluated by inspecting Quality Control (QC) flags and variables in processed data.

Data Processing Algorithms

The first program processes the raw (a0) data to produce intermediate (a1) data files. The averaging time for calculations can be varied to produce equipment center (EC) average values for each ½ hour (other averaging times can be requested of 1, 2, and 4 hr). The calculation is performed as follows:

From a0 to a1:

1. Read in raw data and convert to physical units (u,v,w [m/s], T sonic [C], CO_2 and H_20 [mmol/m^{-3}]).

2. Shift the CO_2 and H_20 signals back by (2 - 3 samples) to correct for a fixed time lag in the LI-7500 analyzer.

Identify and remove spikes from data using 100-second running mean filter. Spikes are identified as data points with values more than a set number of standard deviations away from running mean. Spike data are given value of running mean and are not used to update mean. Spikes are counted and the mean value of the spikes is calculated.

3. Calculate statistics (mean, variance, skewness, and kurtosis) of each variable and covariances between all signal pairs.

4. Calculate 2-D coordinate rotation to zero mean w and v and apply to vector and covariance quantities.

5. Write out results.

From a1 to b1: processes intermediate (a1) files to produce estimates of turbulent fluxes with initial QC flags as follows:

1. Compute turbulent fluxes of CO_2 and H_2O including appropriate Webb-Pearmann-Leuning corrections (Webb et al, 1980) for sensible and latent heat (Webb et al, 1980).

2. Inspect and flag data falling outside of acceptable limits based on variance, spike counts, and turbulence conditions u*.

3. Write out results.

From b1 to metb1:

1. For the 4-m systems, merge meteorological data with b1 data file.

Eddy Covariance Calculations

The algorithm that computes the turbulent fluxes (a1tob1) for the data collected at 4 m uses the air temperature, pressure, and relative humidity from meteorological sensors to calculate the density and specific heat. However, at present, the 25 and 60 m systems use the virtual temperature measured by the anemometer and the H_2O density measured by the IRGA to estimate air density and specific heat, assuming a constant pressure of 98 kPa. This will cause a small errors in cases where pressure or temperature are slightly different from the measured values.

No corrections are made for loss of spectral energy due to sensor separation. Using the work of Moore (1986), we have estimated these corrections to be in the range of 3-7% for most conditions at 4 m above the crops, but it is unlikely to be significant for the measurements at 25 and 60 m.

The fluxes only reflect turbulent fluxes and do not include corrections for storage of CO_2, H_2O, or heat in the air between the sensor and the land surface. Although this is unlikely to be an important correction for the 4-m system, this correction is often significant for the 60-m system. We are working to incorporate data from a precision gas system to include a storage correction for the 25- and 60-m heights.

Soil Temperature and Moisture

Soil temperature sensors were installed at the following depths:

T1, T4 = 25 cm; T2, T5= 15 cm; T3, T6 = 5 cm

Soil moisture sensors were installed at the following times:

July 2001: M1, M3, M5, M7 = 15 cm; M2, M4, M6, M8 = 5 cm

December 2002- present: M1, M3, M5, M7 = 25 cm; M2, M4, M6, M8 = 5 cm

A large temperature sensitivity was observed in the soil moisture sensors exhibit. This is evident in sensors located in shallow soil with large temperature variations. This has not been corrected by processing algorithm to date. This correction will be included in future files. People interested in performing their own corrections may want to consider using the diurnal soil temperature variations to diurnal variations in moisture signals.

6.2 Data Reviews by Instrument Mentor

Visual QC frequency: daily to weekly

QC delay: typically 1-2 days

QC type: -

Instrument mentor Marc Fischer and data processing assistant Igor Pesenson routinely view graphical displays produced at Lawrence Berkeley National Laboratory (LBNL). The displays include graphs of CO_2, H_2O, sensible fluxes, mean and variance of CO_2 concentration (not corrected for barometric pressure) and wind speed.

6.3 Data Assessments by Site Scientist/Data Quality (DQ) Office

All DQ Office and most Site Scientist techniques for checking have been incorporated within DQ HandS and can be viewed there.

6.4 Value-Added Procedures and Quality Measurement Experiments

None at present. A gap-filled data file is being developed.

7. Instrument Details

7.1 Detailed Description

7.1.1 List of Components

Components for Eddy Covariance Calculations:

- 3-D Sonic Anemometer, Gill Solent Windmaster Pro
  Orthogonal wind velocities u, v, and w
  Range: ± 20 m/s
  Accuracy: u,v =1.5% root mean square (RMS) error, w =3% RMS error
  Resolution: 0.01 m/s
- Sonic temperature (from speed of sound (SOS))
  Range: -40 to +60 deg C (307-367 m s-1)
  Accuracy: 3% RMS error in SOS
  Resolution: 0.02 deg C

Infrared Gas Analyzer, Licor Inc. LI-7500 (see http://env.licor.com/)

- CO_2 density
  Range: 0 to 110 mmol/m^3;
  Accuracy: ~ 1% (limited by calibration procedure)
  Precision: ~ 4 umol/m^3 (typical RMS instrument noise)

- H20 density
  Range: 0 to 2000 mmol m^{-3}
  Accuracy: ~ 1% (limited by calibration)
  Precision: 0.14 mmol/m^3 (typical RMS instrument noise)

Data collection system

- 266 - 600 MHz PC clone
- Data collection software:
  ~ 9/11/2000 - 12/19/2001. Data collection performed with gillsonic.c running under MS Windows NT (written in C Programming language for MS-DOS at NOAA-ATDD by Tilden Meyers and modified for use at ARM).

  12/20/2001 - 12/19/2002. Data collection performed with WinfluxWMP.cpp software running under MS Windows NT (written in C++ by Joe Verfaillie at CSU San Diego).
  12/19/2002 - present. Data collection performed with sonic-irga.c software running under Redhat 7.3 (written in C by Ed Dumas at NOAA-ATDD). Note that the data collection system also collects and stores digital serial data from the IRGA.

Table 2.

Components for Meteorological and Soil Measurements Included in 4-m Data Sets**:**

Variable measured	Instrument
Mean horizontal wind speed and direction	Climatronics CS800-12 wind set
Temperature and relative humidity profiles	Vaisala Humiter 50Y (2, 3 m)
Mean atmospheric pressure	Vaisala PTB101B barometer
Soil heat flux	REBS HFT3 soil heat flux plates (4)
Soil temperature profiles	Type E thermocouples (6)
Soil moisture profiles	Decagon ECHO soil moisture sensors (8)
Photosynthetically Active Radiation	LiCor LI-190SA quantum sensor
Downwelling Short Wave Radiation (0.4-11 microns)	LiCor LI-200SA pyranometer
Upwelling and downwelling radiation (0.3 mm – 2.8 mm and 5 mm – 50 mm)	Kipp & Zonen CNR-1 radiometer
Net radiation	Kipp & Zonen NR-lite net radiometer
Summed precipitation	Texas Instruments TE525 tipping bucket rain gage
Data Logger	Campbell CR23x (some systems have CR10x)

7.1.2 System Configuration and Measurement Methods

Pairs of anemometers and IRGAs are located on and near the CF 60-m tower. Data from the anemometer are transmitted to a personal computer (PC) in an instrument shed at the base of the tower. The PC collects and stores the serial binary data stream from the sonic anemometer and IRGA (for more details, see data collection system notes below). The raw data are transferred to LBNL, processed into the ARM Archive format, and inspected for problems on a daily basis. Processed files are sent to the ARM Archive using the Site Transfer Suite on a weekly basis.

7.1.3 Specifications

This section is not applicable to this instrument.

7.2 Theory of Operation

Turbulent fluxes are calculated using standard methods in biometeorology. See Section 7.7, Citable References for discussions.

The 3-D sonic anemometer uses three pairs of orthogonal ultrasonic transmit/receive transducers to measure the transit time of sound signals traveling between the transducer pairs. The wind speed along each transducer axis is determined from the difference in transit times. The sonic temperature is computed from the speed of sound, which is determined from the average transit time along the vertical axis. A pair of measurements are made along each axis 100 times per second. Ten measurements are averaged to produce 10 wind measurements along each axis and 10 temperatures each second.

The IRGA measures CO_2 and H_2O densities by detecting the absorption of infrared radiation by water vapor in the light path. Details of the IRGA operation and performance can be obtained from Licor Env. Inc. (http://env.licor.com/PDF_Files/LI7500.pdf).

Data are collected on a standard personal computer. Data are collected in ½-hour intervals, using the computer clock start as a time reference. Each ½-hour data file has a timestamp reflecting the start time of the file. The computer clock is updated on a regular basis using time server software. The daily collection of 48 raw data files are downloaded from the data collection computer to a processing computer at the LBNL on a daily basis and reduced to produce eddy covariance estimates of turbulent fluxes. A set of data processing algorithms are used to create files suitable for inspection and ingest into the ARM data archive.

7.3 Calibration

This section is not applicable to this instrument.

7.3.1 Theory

The sonic anemometer does not require maintenance or calibration. The IRGA offset and gain need to be calibrated on a periodic basis. The IRGA is calibrated by introducing gas of know concentration into a calibration hood that surrounds the light path over which infrared absorption is measured. The offset is typically calibrated using dry N_2 from a gas bottle. The gain of the CO_2 and H_2O channels are calibrated using a bottle with a known concentration of CO_2 and flow from a H_2O vapor generator (e.g. Licor Inc. LI-610 Dew Point Generator).

7.3.2 Procedures

This section is not applicable to this instrument.

7.3.3 History

The system in longest continuous operation is the system at 60 m on the 60-m tower. The calibration interval for that system is:

October, 18, 2000
July, 13, 2001
December, 18, 2001
December, 20, 2002; replaced.

The portable flux systems are calibrated before each portable deployment period.

7.4 Operation and Maintenance

The sonic anemometer does not require maintenance or calibration. The IRGA offset and gain are calibrated on a periodic basis following the manufacturers recommended procedure.

7.4.1 User Manual

This section is not applicable to this instrument.

7.4.2 Routine and Corrective Maintenance Documentation

This section is not applicable to this instrument.

7.4.3 Software Documentation

General description of the data product formats can be found in the Data Description File.

7.4.4 Additional Documentation

This section is not applicable to this instrument.

7.5 Glossary

Also see the ARM Glossary.

7.6 Acronyms

CF: Central Facility
DQ: Data Quality
EC: equipment center
IRGA: infrared gas analizer
LBNL: Lawrence Berkeley National Laboratory
PC: personal computer
RMS: root mean square
SGP: Southern Great Plains
SOS: sound of speed
QA: Quality Assurance
QC: Quality Control

Also see the ARM Acronyms and Abbreviations.

7.7 Citable References

Kaimal, J.C., Finnigan, J.J., 1994. Atmospheric Boundary Layer Flows: Their Structure and Measurement. Oxford University Press, New York

Moore, C.J., 1986. Frequency Response Corrections for Eddy Correlation Systems. Boundary-Layer Meteorol. 37, 17-35

Paw U, K.T., Baldocchi, D.D., Meyers, T.P., Wilson, K.B., Correction of Eddy-Covariance Measurements Incorporating Both Advective Effects and Density Fluxes. Boundary-Layer Meteorol. 97,487-511

Webb, E.K., Pearman, G.I., and Leuning, R., 1980. Correction of Flux Measurements for Density Effects due to Heat and Water Vapour Transfer. Quart. J. Roy. Meteorol. Soc. 106, 85-100