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Carbon Dioxide Flux Measurement System (CO2FLX) Instrument Handbook

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ARM

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Overview

The main body of this handbook covers the CO2FLX system deployed by ARM from 2015 to the present.

The appendix provides a handbook for an earlier version of the system that was in use from 2002 to 2015, at which time a major redesign of the system occurred.

Acronyms and Abbreviations

3D	three-dimensional
ARM	Atmospheric Radiation Measurement
C1	Central Facility
DO2FLX	carbon dioxide flux measurement system
IRGA	infrared gas analyzer
NetCDF	Network Common Data Form
PAR	photosynthetically active radiation
QC	quality control
RF	radio frequency
RH	relative humidity
rms	root mean square
SGP	Southern Great Plains
SOS	speed of sound
VDC	voltage, direct current

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Carbon dioxide flux measurement system (CO2FLX)

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4.0 Instrument Description

The carbon dioxide flux measurement system (CO2FLX) provides half-hour (30-minute)-averaged turbulent fluxes of mass, momentum, and energy. Fluxes are calculated using the eddy covariance technique which require high-frequency (10 Hz) observations of wind speed using a sonic anemometer and a scalar of interest such as carbon dioxide (CO_2) and water vapor (H_2O) concentrations using an infrared gas analyzer. Turbulent fluxes for CO2FLX are collected at three heights (4, 25, 60 m) at the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Southern Great Plains (SGP) Central Facility (C1). Observations began in 2002. In July 2015, the CO2FLX became an ARM baseline system. At the time of this transition, the infrared gas analyzers at the 25 and 60-m heights were removed.

In addition to the turbulent flux observations, the CO2FLX datastream includes meteorological, radiation, and below-ground observations.

This document focuses on the current CO2FLX system (after July 2015). Please refer to the previous instrument handbook for details regarding the historical CO2FLX observations.

5.0 Measurements Taken

The table below captures the direct observations taken by sensors in the CO2FLX system.

Table 1. List of instruments and associated variables.

Instrument	Manufacturer	Description	Variables
R3-50	Gill Instruments	3D sonic anemometer	u, v, w winds; sonic temperature
LI-7500RS	LI-COR	Infrared gas analyzer	CO_2 and H_2O concentrations; ambient temperature and pressure
CNR4	Kipp & Zonen	Four-component net radiometer	upwelling/downwelling shortwave radiation; upwelling/downwelling longwave radiation
PQS1	Kipp & Zonen	photosynthetically active radiation (PAR) sensor	upwelling/downwelling PAR

Instrument	Manufacturer	Description	Variables
SPN1	Delta-T	sunshine pyranometer	downwelling direct, diffuse, and total shortwave radiation
SI-111	Apogee	infrared thermometer	surface temperature
HFP01SC	Hukseflux	self-calibrating soil heat flux plates	soil heat flux
CS655	Campbell Scientific	12-cm soil moisture and temperature sensor	volumetric water content, soil electrical conductivity, soil temperature, soil permittivity
PTB110	Vaisala	barometric pressure	atmospheric pressure
TR-525M	Texas Electronics	tipping bucket rain gauge	precipitation
41382VC	R.M. Young	air temperature and relative humidity	ambient air temperature, relative humidity

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

CO2FLX data are available as daily files from ARM Data Discovery (https://adc.arm.gov/discovery). a1 files contain the raw high-frequency observations (10 Hz) from the sonic anemometer and infrared gas analyzer. b1 files contain 30-minute-averaged values.

6.2 Data Ordering

A large number (~20) of datastreams are associated with CO2FLX. The CO2FLX datastream names and associated variables have changed over time. Table 2 delineates the datastream names before and after July 2015. Tables 3 and 4 provide a brief description of each datastream as well as a comprehensive variable listing.

Table 2. Datastream names by date.

Datastream names pre-July 2015	Datastream names post-July 2015
sgp30co2flx4mC1.a1 sgp30co2flx25mC1.a1 sgp30co2flx60mC1.a1 sgp30co2flx4mC1.b1 sgp30co2flx25mC1.b1 sgp30co2flx60mC1.b1 sgp30co2flx4mmetC1.b1	sgpco2flxgas4mC1.a1 sgpco2flxwind4mC1.a1 sgpco2flxwind25mC1.a1 sgpco2flxwind60mC1.a1 sgpco2flx4mC1.b1 sgpco2flx25mC1.b1 sgpco2flx60mC1.b1 sgpco2flxrad4mC1.b1 sgpco2flxsoil4mC1.b1 sgpco2flxsoilaux4mC1.b1 sgpco2flxwindC1.b1

From 2015-07-22 to present, the CO2FLX observations are reported in the following datastreams:

Table 3. Datastream variables for CO2FLX from July 2015 to present.

Datastream name	Brief description	Variables reported
sgpco2flxgas4mC1.a1	high-frequency (10 Hz) raw observations from the infrared gas analyzer at 4m.	'co2_concentration' 'h2o_concentration' 'air_temperature' 'pressure_gas_analyzer' 'reference_signal_strength' 'diagnostic_flag'
sgpco2flxwind4mC1.a1	high-frequency (10 Hz) raw observations from the sonic anemometer at 4 m.	'u_wind' 'v_wind' 'w_wind' 'sonic_temperature'
sgpco2flxwind25mC1.a1	high-frequency (10 Hz) raw observations from the sonic anemometer at 25 m.	'u_wind' 'v_wind' 'w_wind' 'sonic_temperature'
sgpco2flxwind60mC1.a1	high-frequency (10 Hz) raw observations from the sonic anemometer at 60 m.	'u_wind' 'v_wind' 'w_wind' 'sonic_temperature'
sgpco2flx4mC1.b1	30-minute-averaged fluxes and related statistics and intermediate products from the eddy covariance processing (4-m level).	'momentum_flux' 'qc_momentum_flux' 'random_error_momentum_flux' 'sensible_heat_flux' 'qc_sensible_heat_flux' 'random_error_sensible_heat_flux' 'latent_heat_flux' 'qc_latent_heat_flux' 'random_error_latent_heat_flux' 'qc_random_error_latent_heat_flux' 'co2_flux' 'qc_co2_flux' 'random_error_co2_flux' 'qc_random_error_co2_flux' 'h2o_flux' 'qc_h2o_flux' 'random_error_h2o_flux' 'qc_random_error_h2o_flux' 'co2_molar_density' 'qc_co2_molar_density' 'co2_mole_fraction' 'qc_co2_mole_fraction' 'co2_mixing_ratio'

Datastream name	Brief description	Variables reported
		'qc_co2_mixing_ratio' 'co2_time_lag' 'co2_time_lag_state' 'h2o_molar_density' 'qc_h2o_molar_density' 'h2o_mole_fraction' 'qc_h2o_mole_fraction' 'h2o_mixing_ratio' 'qc_h2o_mixing_ratio' 'h2o_time_lag' 'h2o_time_lag_state' 'sonic_temperature' 'air_temperature' 'air_pressure' 'air_density' 'air_heat_capacity' 'air_molar_volume' 'evapotranspiration_rate' 'water_vapor_density' 'water_vapor_partial_pressure' 'water_vapor_partial_pressure_saturation' 'specific_humidity' 'relative_humidity' 'water_vapor_pressure_deficit' 'dew_point_temperature' 'eastward_wind' 'northward_wind' 'vertical_wind' 'u_wind_rotated' 'v_wind_rotated' 'w_wind_rotated' 'wind_speed' 'max_wind_speed' 'wind_direction' 'yaw' 'pitch' 'friction_velocity' 'turbulent_kinetic_energy' 'monin_obukov_length' 'monin_obukov_stability_parameter' 'bowen_ratio' 'scaling_temperature' 'momentum_flux_uncorrected' 'momentum_flux_spectral_correction_factor' 'sensible_heat_flux_uncorrected' 'sensible_heat_flux_spectral_correction_factor' 'latent_heat_flux_uncorrected' 'latent_heat_flux_spectral_corre

Datastream name	Brief description	Variables reported
		ction_factor' 'co2_flux_uncorrected' 'co2_flux_spectral_correction_f actor' 'h2o_flux_uncorrected' 'h2o_flux_spectral_correction_f actor' 'eastward_wind_spikes' 'northward_wind_spikes' 'vertical_wind_spikes' 'sonic_temperature_spikes' 'co2_flux_spikes' 'h2o_flux_spikes' 'chopper_flag' 'detector_flag' 'pll_flag' 'sync_flag' 'mean_value_RSSI' 'wind_speed_variance' 'cross_wind_speed_variance' 'vertical_wind_variance' 'wind_direction_variance' 'scaling_temperature_variance' 'co2_flux_variance' 'qc_co2_flux_variance' 'h2o_flux_variance' 'qc_h2o_flux_variance' 'scaling_temperature_covarianc e' 'co2_flux_covariance' 'qc_co2_flux_covariance' 'h2o_flux_covariance' 'qc_h2o_flux_covariance'
sgpco2flx25mC1.b1	30-minute-averaged fluxes and related statistics and intermediate products from the eddy covariance processing (25-m level).	'momentum_flux' 'qc_momentum_flux' 'random_error_momentum_flux ' 'sensible_heat_flux' 'qc_sensible_heat_flux' 'random_error_sensible_heat_fl ux' 'sonic_temperature' 'air_density' 'air_heat_capacity' 'air_molar_volume' 'eastward_wind' 'northward_wind' 'vertical_wind' 'u_wind_rotated' 'v_wind_rotated' 'w_wind_rotated' 'wind_speed'

Datastream name	Brief description	Variables reported
		'max_wind_speed' 'wind_direction' 'yaw' 'pitch' 'friction_velocity' 'turbulent_kinetic_energy' 'monin_obukov_length' 'monin_obukov_stability_parameter' 'bowen_ratio' 'scaling_temperature' 'momentum_flux_uncorrected' 'momentum_flux_spectral_correction_factor' 'sensible_heat_flux_uncorrected' 'sensible_heat_flux_spectral_correction_factor' 'eastward_wind_spikes' 'northward_wind_spikes' 'vertical_wind_spikes' 'sonic_temperature_spikes' 'wind_speed_variance' 'cross_wind_speed_variance' 'vertical_wind_variance' 'wind_direction_variance' 'scaling_temperature_variance' 'scaling_temperature_covariance'
sgpco2flx60mC1.b1	30-minute-averaged fluxes and related statistics and intermediate products from the eddy covariance processing (60-m level).	'momentum_flux' 'qc_momentum_flux' 'random_error_momentum_flux' 'sensible_heat_flux' 'qc_sensible_heat_flux' 'random_error_sensible_heat_flux' 'sonic_temperature' 'air_density' 'air_heat_capacity' 'air_molar_volume' 'eastward_wind' 'northward_wind' 'vertical_wind' 'u_wind_rotated' 'v_wind_rotated' 'w_wind_rotated' 'wind_speed' 'max_wind_speed' 'wind_direction' 'yaw' 'pitch'

Datastream name	Brief description	Variables reported
		'friction_velocity' 'turbulent_kinetic_energy' 'monin_obukov_length' 'monin_obukov_stability_parameter' 'bowen_ratio' 'scaling_temperature' 'momentum_flux_uncorrected' 'momentum_flux_spectral_correction_factor' 'sensible_heat_flux_uncorrected' 'sensible_heat_flux_spectral_correction_factor' 'eastward_wind_spikes' 'northward_wind_spikes' 'vertical_wind_spikes' 'sonic_temperature_spikes' 'wind_speed_variance' 'cross_wind_speed_variance' 'vertical_wind_variance' 'wind_direction_variance' 'scaling_temperature_variance' 'scaling_temperature_covariance'
sgpco2flxrad4mC1.b1	30-minute-averaged values from the ‘radiation satellite’ datalogger.	'battery_minimum' 'panel_temperature' 'downwelling_shortwave' 'qc_downwelling_shortwave' 'downwelling_longwave' 'qc_downwelling_longwave' 'upwelling_shortwave' 'qc_upwelling_shortwave' 'upwelling_longwave' 'qc_upwelling_longwave' 'CNR4_temperature' 'qc_CNR4_temperature' 'upwelling_photosynthetic_active_radiation' 'qc_upwelling_photosynthetic_active_radiation' 'downwelling_photosynthetic_active_radiation' 'qc_downwelling_photosynthetic_active_radiation' 'downwelling_direct_shortwave' 'qc_downwelling_direct_shortwave' 'downwelling_diffuse_shortwave' 'qc_downwelling_diffuse_short

Datastream name	Brief description	Variables reported
		wave' 'total_solar' 'qc_total_solar' 'si_sensor_body_temperature' 'qc_si_sensor_body_temperatur e' 'thermopile_infrared_detector' 'qc_thermopile_infrared_detect or' 'surface_temperature' 'qc_surface_temperature'
sgpco2flxsoilC1.b1	30-minute-averaged values from the soil satellite' datalogger.	'measured_soil_heat_flux' 'qc_measured_soil_heat_flux' 'calibrated_soil_heat_flux' 'qc_calibrated_soil_heat_flux' 'raw_volumetric_water_content' 'qc_raw_volumetric_water_cont ent' 'raw_soil_electrical_conductivit y' 'qc_raw_soil_electrical_conduct ivity' 'raw_soil_temperature' 'qc_raw_soil_temperature' 'raw_permittivity' 'qc_raw_permittivity' 'raw_signal_oscillation_period' 'qc_raw_signal_oscillation_peri od' 'raw_voltage_ratio' 'qc_raw_voltage_ratio' 'calibration_flag'
sgpco2flxsoilauxC1.b1	30-minute-averaged values from the datalogger on the 4-m eddy covariance tripod.	'panel_temperature' 'battery_minimum' 'atmospheric_pressure' 'ambient_air_temperature' 'relative_humidity' 'precipitation_rate' 'auxiliary_volumetric_water_co ntent' 'qc_auxiliary_volumetric_water _content' 'auxiliary_soil_electrical_condu ctivity' 'qc_auxiliary_soil_electrical_co nductivity' 'auxiliary_soil_temperature' 'qc_auxiliary_soil_temperature' 'auxiliary_permittivity' 'qc_auxiliary_permittivity' 'auxiliary_signal_oscillation_pe

Datastream name	Brief description	Variables reported
		riod' 'qc_auxiliary_signal_oscillation_period' 'auxiliary_voltage_ratio' 'qc_auxiliary_voltage_ratio'
sgpco2flxwindC1.b1	combined wind statistics from the sonic anemometers at 4, 25, 60-m levels.	'vertical_wind_4m' 'wind_speed_4m' 'qc_wind_speed_4m' 'max_wind_speed_4m' 'wind_direction_4m' 'qc_wind_direction_4m' 'wind_speed_variance_4m' 'cross_wind_speed_variance_4m' 'vertical_wind_variance_4m' 'wind_direction_variance_4m' 'vertical_wind_25m' 'wind_speed_25m' 'qc_wind_speed_25m' 'max_wind_speed_25m' 'wind_direction_25m' 'qc_wind_direction_25m' 'wind_speed_variance_25m' 'cross_wind_speed_variance_25m' 'vertical_wind_variance_25m' 'wind_direction_variance_25m' 'vertical_wind_60m' 'wind_speed_60m' 'qc_wind_speed_60m' 'max_wind_speed_60m' 'wind_direction_60m' 'qc_wind_direction_60m' 'wind_speed_variance_60m' 'cross_wind_speed_variance_60m' 'vertical_wind_variance_60m' 'wind_direction_variance_60m'

Prior to 2015-07-20, the CO2FLX observation can be found in the following datastreams:

Table 4. Datastream variables for CO2FLX before July 2015.

Datastream name	Brief description	Variables reported
sgp30co2flx4mC1.a1 sgp30co2flx25mC1.a1 sgp30co2flx60mC1.a1	30-minute averages and higher-order statistics of high-frequency eddy covariance observations at each level (4, 25, 60 m).	'mean_unrot_u' 'mean_unrot_v' 'mean_unrot_w' 'mean_t' 'mean_q' 'mean_c' 'var_unrot_u' 'var_unrot_v' 'var_unrot_w' 'var_t' 'var_q' 'var_c' 'skew_unrot_u' 'skew_unrot_v' 'skew_unrot_w' 'skew_t' 'skew_q' 'skew_c' 'kurt_unrot_u' 'kurt_unrot_v' 'kurt_unrot_w' 'kurt_t' 'kurt_q' 'kurt_c' 'cvar_unrot_uv' 'cvar_unrot_uw' 'cvar_unrot_vw' 'cvar_unrot_ut' 'cvar_unrot_uq' 'cvar_unrot_uc' 'cvar_unrot_vt' 'cvar_unrot_vq' 'cvar_unrot_vc' 'cvar_unrot_wt' 'cvar_unrot_wq' 'cvar_unrot_wc' 'cvar_tq' 'cvar_tc' 'cvar_qc' 'theta' 'phi' 'mean_rot_u' 'mean_rot_v' 'mean_rot_w' 'var_rot_u' 'var_rot_v' 'var_rot_w' 'cvar_rot_uv'

Datastream name	Brief description	Variables reported
		'cvar_rot_uw' 'cvar_rot_vw' 'cvar_rot_ut' 'cvar_rot_uq' 'cvar_rot_uc' 'cvar_rot_vt' 'cvar_rot_vq' 'cvar_rot_vc' 'cvar_rot_wt' 'cvar_rot_wq' 'cvar_rot_wc' 'nspk_unrot_u' 'nspk_unrot_v' 'nspk_unrot_w' 'nspk_t' 'nspk_q' 'nspk_c' 'mean_spk_unrot_u' 'mean_spk_unrot_v' 'mean_spk_unrot_w' 'mean_spk_t' 'mean_spk_q' 'mean_spk_c' 'mean_p'
sgp30co2flx4mC1.b1 sgp30co2flx25mC1.b1 sgp30co2flx60mC1.b1	30-minute fluxes, correction factors, and eddy covariance terms at each level (4, 25, 60 m).	'fc_corr' 'qc_fc_corr' 'fc_wpl_h' 'qc_fc_wpl_h' 'fc_wpl_le' 'qc_fc_wpl_le' 'h' 'qc_h' 'le' 'qc_le' 'zm' 'mean_rot_u' 'qc_mean_rot_u' 'mean_t' 'qc_mean_t' 'mean_q' 'qc_mean_q' 'mean_c' 'qc_mean_c' 'mean_p' 'qc_mean_p' 'var_rot_u' 'qc_var_rot_u' 'var_rot_v' 'qc_var_rot_v' 'var_rot_w' 'qc_var_rot_w' 'var_t'

Datastream name	Brief description	Variables reported
		'qc_var_t' 'var_q' 'qc_var_q' 'var_c' 'qc_var_c' 'wdir' 'qc_wdir' 'theta' 'qc_theta' 'phi' 'qc_phi' 'ustar' 'qc_ustar' 'Lmoni' 'qc_Lmoni'
sgp30co2flx4mmetC1.b1	30-minute fluxes from 4-m level including meteorological, radiation, and soil sensor observations.	'fc_corr' 'qc_fc_corr' 'fc_wpl_h' 'qc_fc_wpl_h' 'fc_wpl_le' 'qc_fc_wpl_le' 'h' 'qc_h' 'le' 'qc_le' 'zm' 'mean_rot_u' 'qc_mean_rot_u' 'mean_t' 'qc_mean_t' 'mean_q' 'qc_mean_q' 'mean_c' 'qc_mean_c' 'mean_p' 'qc_mean_p' 'var_rot_u' 'qc_var_rot_u' 'var_rot_v' 'qc_var_rot_v' 'var_rot_w' 'qc_var_rot_w' 'var_t' 'qc_var_t' 'var_q' 'qc_var_q' 'var_c' 'qc_var_c' 'wdir' 'qc_wdir' 'theta' 'qc_theta'

Datastream name	Brief description	Variables reported
		'phi' 'qc_phi' 'ustar' 'qc_ustar' 'Lmoni' 'qc_Lmoni' 'bar_pres' 'qc_bar_pres' 't_air_upper' 'qc_t_air_upper' 't_air_lower' 'qc_t_air_lower' 'rh_upper' 'qc_rh_upper' 'rh_lower' 'qc_rh_lower' 'z_upper' 'z_lower' 'mean_g_soil' 'qc_mean_g_soil' 'stderr_mean_g_soil' 'z_g_soil' 'r_net' 'qc_r_net' 'r_tot' 'qc_r_tot' 'r_down_short_hemisp' 'qc_r_down_short_hemisp' 'r_up_short_hemisp' 'qc_r_up_short_hemisp' 'r_down_long_hemisp' 'qc_r_down_long_hemisp' 'r_up_long_hemisp' 'qc_r_up_long_hemisp' 't_rad' 'qc_t_rad' 'ppfd' 'qc_ppfd' 'zrad' 'mean_t_soil_upper' 'qc_mean_t_soil_upper' 'stderr_mean_t_soil_upper' 'z_t_soil_upper' 'mean_t_soil_middle' 'qc_mean_t_soil_middle' 'stderr_mean_t_soil_middle' 'z_t_soil_middle' 'mean_t_soil_lower' 'qc_mean_t_soil_lower' 'stderr_mean_t_soil_lower' 'z_t_soil_lower' 'mean_m_soil_upper' 'qc_mean_m_soil_upper'

Datastream name	Brief description	Variables reported
		'stderr_mean_m_soil_upper' 'z_m_soil_upper' 'mean_m_soil_lower' 'qc_mean_m_soil_lower' 'stderr_mean_m_soil_lower' 'z_m_soil_lower' 'precip' 'qc_precip' 'ppfd_up' 'qc_ppfd_up'

6.3 Data Plots

Near-real-time dynamic data plots are available at https://dq.arm.gov/dq-plotbrowser/. Additionally, the instrument mentors maintain an independent data visualization dashboard for routine quality assessment.

6.4 Data Quality

Many variables have associated quality control (QC) flags included in the datastream (only for b1-level data). The QC flag for a given variable has 'qc_' at the start of the variable name. The QC flag descriptions are included in the NetCDF file: either in the global file attribute or in variable-specific attributes.

The QC flags for turbulent fluxes (H, LE, co2_flux, etc.) have flags 1-9, which correspond to micrometeorological test results based on Foken et al. (2004). In this test rubric, lower values are better for satisfying assumptions used for eddy covariance flux calculations. All variables measured by or derived from the infrared gas analyzer (IRGA) also have a flag 10, which is triggered when the sensing path is not clear (dirt, precipitation, etc.).

No QC flags are generated for the unprocessed a1-level data. The sonic anemometers and IRGA have exposed sensing paths that are sensitive to environmental contamination including precipitation. The relative cleanliness of the IRGA sensing path is reported in the 'reference_signal_strength' variable. Periods when the signal strength is below 93 should be treated cautiously.

6.5 Instrument Mentor Monthly Summary

Instrument mentors review the CO2FLX data every few days using our in-house graphical time series figures. Known issues or loss of data are captured in Data Quality Reports (DQR).

7.0 Technical Specification

All instruments deployed as part of the CO2FLX system are commercially available. Cited technical specifications in this section will be those reported by the instrument manufacturers. Technical specification will focus on the eddy covariance sensors (sonic anemometer, gas analyzer) for brevity.

7.1 Sonic Anemometer

The Gill R3-50 sonic anemometer is used for wind measurements at 4, 25, 60 m.

Wind measurement specifications:

Measurement Rate: 50 s-1 (Full 3-axis measurement)
Data Output Rates: From 0.4 to 50 s-1
Wind Speed Range: 0 to 45 ms-1
Wind Speed Accuracy: <1% rms
Wind Speed Resolution: 0.01 ms-1
Wind Speed Offset: <±0.01ms-1

Speed-of-sound measurement specifications:

Measurement Rate: 50 s-1 (Synchronous to wind measurement)
SOS Range: 300-370 ms-1
SOS Accuracy: <±0.5% (For wind speeds <30 ms-1)
SOS Resolution: 0.01ms-1

7.2 Infrared Gas Analyzer (IRGA)

The LI-7500RS infrared gas analyzer is used for observations of CO_2 and H_2O at 4m only.

CO_2 measurement specifications:

Calibration Range: 0 to 3000 µmol mol-1
Accuracy: Within 1% of reading
Zero Drift (per °C):
±0.1 ppm typical
±0.3 ppm maximum
RMS Noise (typical @ 370 ppm CO_2):
@5 Hz: 0.08 ppm
@10 Hz: 0.11 ppm
@20 Hz: 0.16 ppm
Gain Drift (% of reading per °C @ 370 ppm):
±0.02% typical
±0.1% maximum
Direct Sensitivity to H_2O (mol CO_2 mol-1 H_2O):
±2.00E-05 typical
±4.00E-05 maximum

H_2O measurement specifications:

Calibration Range: 0 to 60 mmol mol-1
Accuracy: Within 1% of reading
Zero Drift (per °C):
±0.03 mmol mol-1 typical
±0.05 mmol mol-1 maximum
RMS Noise (typical @ 10 mmol mol-1 H_2O):
@5 Hz: 0.0034 mmol mol-1
@10 Hz: 0.0047 mmol mol-1

@20 Hz: 0.0067 mmol mol-1
Gain Drift (% of reading per °C @ 20 mmol mol-1):
±0.15% typical
±0.30% maximum
Direct Sensitivity to CO_2 (mol H_2O mol-1 CO_2):
±0.02 typical
±0.05 maximum

7.3 Input Voltage

Not a critical specification. All CO2FLX instruments operate on 12 VDC or 5 VDC nominal. The radiation and soil stations are supplied via solar panel and a battery.

The R3-50 sonic anemometer accepts input voltage of 9-30 VDC. The LI-7500 accepts input voltage of 10.5 to 30 VDC.

7.4 Input Current

The R3-50 sonic anemometer is specified for <300 mA at 12 VDC. The LI-7500 is specified for 0.6-1.5 A (temperature dependent) at 12 VDC.

8.0 Instrument System Functional Diagram

The CO2FLX system is physically deployed on a few different structures/locations. A brief text description is provided as well as a diagram and photograph.

- The 25 and 60-m instruments are located on a 60-m triangular, guyed tower. The instrument booms can be mechanically lowered for service at ground level. An instrument shed located at the base of the tower houses the primary data acquisition computer.
- The 4-m flux instruments are located on a tripod to the southeast of the 60-m tower. This tripod also includes a datalogger for the T/RH sensor, barometric pressure, rain gauge, and a 6-level soil moisture/temperature profile (co2flxsoilaux). There is line power and data communications to this tripod.
- Below-ground observations are collected at a soil ‘satellite’ station located south of the 4m tripod (co2flxsoil). Four (4) self-calibrating soil heat flux plates and six (6) soil moisture/temperature sensors are located at the soil ‘satellite’. Power is solar/battery. Data communications are via RF radio.
- The radiation sensors are deployed on a remote ‘satellite’ station located south of the soil satellite (co2flxrad). The radiation satellite includes the four-component net radiometer, sunshine sensor, two PAR sensors, and surface temperature observations. Power is solar/battery. Data communications are via RF radio.

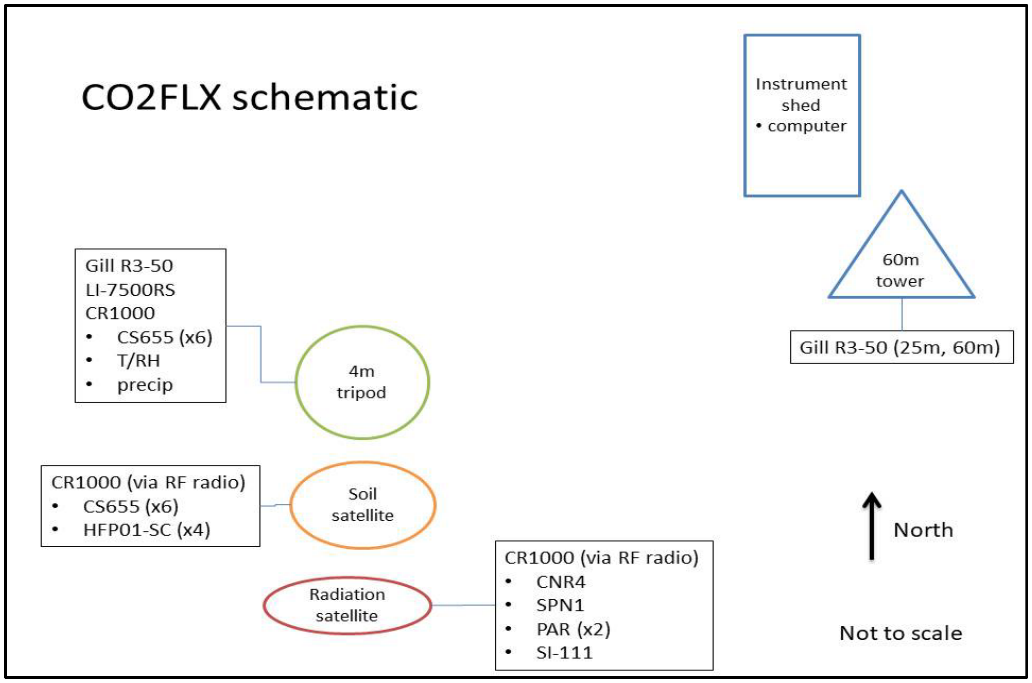

Figure 1. Instrument schematic of CO2FLX.

Figure 2. Photograph of 4 m tripod and soil and radiation satellites. Taken May 2018 by Sebastien Biraud.

9.0 Instrument/Measurement Theory

A brief description of the measurement principles of the eddy covariance sensors (sonic anemometer and infrared gas analyzer) are provided below. A detailed description of the eddy covariance technique is beyond the scope of this document and we refer the read to the Citable References section.

The sonic anemometer uses three pairs of 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 in the light path.

10.0 Setup and Operation of Instrument

The CO2FLX system described in this document was initially installed on 07/20/2015. The initial installation included the sonic anemometers at 25 and 60 m and the 4-m tripod instruments. The soil satellite was installed on 04/07/2016 and the radiation satellite was installed on 05/18/2016.

On the 4m tripod, the sonic anemometer and IRGA are located at 4.55 m and the T/RH sensor is at 4.3 m. The soil moisture/temperature sensors at the 4m tripod (co2flxsoilaux) are deployed in a vertical profile at -0.1, -0.2, -0.3, -0.5, -0.7, and -1 m.

At the soil satellite (co2flxsoil), the soil heat flux plates are all deployed at -0.075 m. The soil moisture/temperature sensors are deployed at two vertical profiles (-0.125, -0.25, -0.38 m).

At the radiation satellite (co2flxrad), the CNR4, PAR sensors, and SPN1 are all deployed at 2.55 m. The infrared thermometer is located at 1m.

11.0 Software

11.1 Data Acquisition Software

The high-frequency data from the sonic anemometer and gas analyzer are sent via serial communications (RS-232) to a Microsoft Windows®-based computer. Serial data is read, synchronized, and written to files using the HuskerFlux software package.

Link to source code repository:
https://github.com/Flux-Dave/HuskerFlux

Data collected on Campbell Scientific dataloggers are retrieved and written to files using LoggerNet software running on a Windows-based computer. This is a commercial software product available from the manufacturer, Campbell Scientific.

11.2 Eddy Covariance Processing Software

All eddy covariance fluxes are calculated using EddyPro, an open-source software package (see links below). Many user-selectable processing options are available in EddyPro.

Link to source code repository:
https://github.com/LI-COR/eddypro-engine

Link to online documentation and pre-compiled executables:
http://www.licor.com/eddypro

12.0 Calibration

All instrument calibrations are performed by the instrument manufacturers following calibration intervals as recommended by the manufacturer.

13.0 Maintenance

SGP site operations conduct daily checks of the CO2FLX system. Both eddy covariance sensors are sensitive to environmental contaminants blocking the sensing path, so routine cleaning is necessary to maintain instrument performance. Similarly, radiation sensors require regular cleaning.

14.0 Safety

The CO2FLX system does not present any particular safety hazards.

The primary safety considerations faced when working with CO2FLX are environmental hazards (weather, stinging insects, etc.). The other safety-related consideration is working at height. ARM SGP site safety protocols should be followed at all times. Hard hats should be worn when working in proximity to the 60m tower.

15.0 Citable References

Aubinet, M, T Vesala, and D Papale. (Eds.). 2012. *Eddy Covariance*. Springer, Dordrecht, Netherlands.

Bagley, JE, LM Kueppers, DP Billesbach, IN Williams, SC Biraud, and MS Torn. 2017. "The Influence of Land Cover on Surface Energy Partitioning and Evaporative Fraction Regimes in the U.S. Southern Great Plains." *Journal Of Geophysical Research − Atmospheres* 122(11): 5793−5807, https://doi.org/10.1002/2017JD026740

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Raz-Yaseef, N, DP Billesbach, ML Fischer, SC Biraud, SA Gunter, JA Bradford, and MS Torn. 2015. “Vulnerability of crops and native grasses to summer drying in the U.S. Southern Great Plains.” *Agriculture, Ecosystems & Environment* 213: 209−218, https://doi.org/10.1016/j.agee.2015.07.021

Appendix A

Carbon Dioxide Flux Measurement System Instrument Handbook (2002-2015)

ARM TR-048

Carbon Dioxide Flux Measurement Systems
Handbook

January 2005

Atmospheric Radiation Measurement
Climate Research Facility
U.S. Department of Energy

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

ARM TR-048

Carbon Dioxide Flux Measurement Systems (CO_2FLX) Handbook

January 2004

M.L. Fischer

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

Contents

Tables

1. General Overview

The Southern Great Plains (SGP) carbon dioxide flux (CO_2 flux) measurement systems provide ½-hour average fluxes of CO_2, H_2O (latent heat), and sensible heat. The fluxes are obtained by the eddy covariance technique, which computes the flux as the mean product of the vertical wind component with CO_2 and H_2O densities, or estimated virtual temperature. A three-dimensional sonic anemometer is used to obtain the orthogonal wind components and the virtual (sonic) temperature. An infrared gas analyzer is used to obtain the CO_2 and H_2O densities. A separate sub-system also collects half average measures of meteorological and soil variables from separate 4-m towers.

2. Contacts

2.1 Mentor

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web page: http://eetd.lbl.gov/env/mlf/

2.2 Instrument Developer

David P. Billesbach, Research Professor
206 L.W. Chase Hall
University of Nebraska
Lincoln, NE 68583
Phone: (402) 472-7961
email: dbillesbach1@unl.edu

For instrument repair and maintenance:

Gill Solent, UK
US Dist. Texas Electronics
Phone: (800) 424-5651
Website: http://www.gill.co.uk/

Licor Environmental
Lincoln, Nebraska
Phone: (800) 447-3576
Website: http://env.licor.com/

Campbell Scientific
Logan, Utah
Phone: (435) 753-2342
Website: http://www.campbellsci.com/

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

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