Long-term carbon dioxide and water flux database, Walnut Gulch Experimental Watershed, Arizona, United States

William E. Emmerich[1] and Charmaine L. Verdugo[1]

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[1] We present the carbon dioxide and water flux data along with associated meteorological data collected by the U.S. Department of Agriculture Agricultural Research Service, Southwest Watershed Research Center, on the Walnut Gulch Experimental Watershed from 1997 through 2006. Measurements were collected from a shrub and grass community using the Bowen ratio energy balance systems and were presented in 20-min time steps. Meteorological and Bowen ratio data were imported into spreadsheets for quality control and calculations of carbon dioxide and water fluxes. The data are available at http://www.tucson.ars.ag.gov/dap/.

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1. Introduction

[2] Carbon dioxide and water fluxes are important components of watershed function. In order to study carbon dioxide and water flux as they exist over the Walnut Gulch Experimental Watershed (WGEW), two sites were selected on the basis of their ecosystem composition, one site being dominated by shrubs and the other a grass dominated plant community. Measurements were made from 1997 through the present at the two sites. The meteorological data and Bowen ratio energy balance systems (BREB) (Model 023/CO_2 Campbell Scientific Inc., Logan, Utah, USA) data are used to calculate carbon dioxide and evapotranspiration (ET) fluxes. (Note: mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA or the author and does not imply its approval to the exclusion of other products that may also be suitable.)

2. Measurement Sites

[3] The shrub site is known as Lucky Hills (110°3′5″W, 31°44′37″N; elevation 1372 m). The soil at this site is Luckyhills series (coarse-loamy, mixed, thermic Ustochreptic Calciorthids) with 3 to 8% slopes [*NRCS Soil Survey*, 2003]. The surface A horizon (0–6 cm) contains 650 g kg^{-1} sand, 290 g kg^{-1} silt, and 60 g kg^{-1} clay with 290 g kg^{-1} coarse fragments >2 mm, 8 g kg^{-1} organic carbon, and 21 g kg^{-1} inorganic carbon. Vegetation is dominated by creosotebush (*Larrea tridentata* (D.C.) Cov.), whitethorn Acacia (*Acacia constricta* Benth. (Fabaceae)), and tarbush (*Flourensia cernua* D.C. (Asteraceae)) [*King et al.*, 2008]. The grass site is identified as Kendall (109°56′8″W, 31°44′10″N; elevation; 1526 m). The soils at the Kendall site are a complex of Stronghold (coarse-loamy, mixed, thermic Ustollic Calciorthids), Elgin (fine, mixed, thermic, Ustollic Paleargids), and McAllister (fine-loamy, mixed, thermic, Ustollic Haplargids) soils, with Stronghold the dominant soil [*NRCS Soil Survey*, 2003]. Slopes range from 4 to 9%. The Stronghold surface A horizon (0–3 cm) contains 670 g kg^{-1} sand, 160 g kg^{-1} silt, and 170 g kg^{-1} clay with 790 g kg^{-1} coarse fragments >2 mm, 11 g kg^{-1} organic carbon, and 7 g kg^{-1} inorganic carbon. Vegetation is dominated by herbaceous plants, predominately black grama (Bouteloua eriopoda (Torr.) Torr.), sideoats grama (Bouteloua curtipendula (Michx.) Torr.), three-awn (*Aristida sp.*) and cane beardgrass (Bothriochloa barbinodis (Lag.) Herter) [*King et al.*, 2008].

3. Instrumentation and Flux Calculation

[4] Meteorological measurements were measured every 2 s, averaged on a 20-min time step, and stored with a Campbell Scientific Inc. 023/CO_2 Bowen Ratio Energy Balance System (BREB). The complete installation and operation procedures for the BREB system can be found at http://www.campbellscientific.com/documents/manuals/co2bowen.pdf. The BREB systems were placed in locations with a fetch of 200+ m in all directions at the sites. Kendall grass site gradients were measured at 1 m and 2.5 m, and Lucky Hills shrub site at 1.5 m and 3.0 m above the soil surface. Vegetation canopy height at the grass site ranged from 0.4 to 0.7 m during the growing season and at the shrub site maintained an almost constant 1 m height. Atmospheric carbon dioxide and moisture concentrations were measured with an infrared gas analyzer (IRGA) (LI-6262, LI-COR, Inc. Lincoln, Nebraska, USA). Meteorological data obtained are: net radiation from a net radiometer at 3 m height (model Q*7 REBS, Seattle, Washington, USA), soil heat flux from five soil heat flux plates (SHFP) at 8 cm depth (model HFT3 REBS), soil temperature above each heat flux plate at a depth of 5 cm from averaging thermocouples, wind speed and direction from an anemometer/wind vane at a height of 3.4 m (model 03001 R.M. Young Wind Sentry Set R.M.

[1]Southwest Watershed Research Center, Agricultural Research Service, U.S. Department of Agriculture, Tucson, Arizona, USA.

Table 1. Database Parameters on a 20-min Time Step, 1997–2006

Parameters	Units
Location	
Year	
Julian day	
Hour	24 h
Delta CO_2	umol/mol
Delta H_2O	mmol/mol
Delta temperature	deg C
CO2 REF	umol/mol
Air temperature, height 2 m	deg C
Calculated saturated vapor pressure	mbar
Net radiation	W/m^2
Total solar radiation	W/m^2
PAR, UP	$umol/m^2/s$
PAR, DOWN	$umol/m^2/s$
Soil heat flux G1	W/m^2
Soil heat flux G2	W/m^2
Soil heat flux G3	W/m^2
Soil heat flux G4	W/m^2
Soil heat flux G5	W/m^2
Soil temperature, 5 cm	deg C
Relative humidity	%
Wind speed, 3.4 m height	m/s
Wind direction, 0°–360°	deg
Precipitation	mm
Soil heat flux, GO, all SHFP	W/m^2
Latent heat flux, LV	J/g
Bowen ratio	—
Sensible heat flux, H	W/m^2
Evaporation rate	$g/m^2/s$
CO_2 flux rate	$mg/m^2/s$

Young Company, Traverse City, Michigan, USA), and air temperature and relative humidity from a T/RH probe at a height of 2 m (model HMP35C Vaisala, Inc., Woburn, Massachusetts, USA). Net radiometers were calibrated yearly over a grass canopy. All other instruments were calibrated and maintained in accordance with manufacturers' recommendations.

[5] The theory and procedures used in the BREB systems to calculate the fluxes have been presented in detail by *Dugas* [1993] and *Dugas et al.* [1999]. Temperature and water vapor gradients were used to calculate Bowen ratios. Bowen ratio, net radiation, soil heat flux, and soil temperature were used to calculate sensible heat flux. Eddy diffusivity was calculated from sensible heat fluxes and temperature gradients and assumed to be equal for heat, water vapor, and CO_2. Eddy diffusivity could not be calculated when sensible/latent heat flux was in the opposite direction of temperature/water vapor gradients, or when Bowen ratio approached -1.0 [*Ohmura*, 1982]. Under these conditions, eddy diffusivity was calculated by using wind speed, atmospheric stability, and canopy height [*Dugas et al.*, 1999]. This alternative method for calculating eddy diffusivity was used about 12% of the time; primarily at night when gradients and fluxes were minor and hence any errors from the alternative method would have minimal impact on the calculated 24 h flux values. Soil moisture data needed for the soil heat flux calculation was collected and evaluated over a 2-year period using gravimetric and TDR measurements at the start of the study. These data were then used to develop relationships between precipitation and soil moisture. These relationships are now used to estimate soil moisture. For this study, calculated negative CO_2 flux values were considered uptake of CO_2 by the ecosystems.

4. Data Analysis and Quality Control

[6] The stored Bowen ration instrument data from the two measurement sites were transmitted by radio daily to our research station in Tombstone, AZ. From there, they were transferred through an Internet connection to Tucson, AZ. The data were then divided into 5-d increments and inserted into a Quattro® Pro spreadsheet file which had all the formulations to calculate flux of soil heat, latent heat, sensible heat, evapotranspiration rates (ET), and CO_2 rates on the 20-min time step of the data. All instrument and calculated data were graphed in the spreadsheet file and thoroughly reviewed for any instrument problems or data stream collection issues. Instrument data determined to be bad were kept in the set to preserve the measurements collected by the instrumentation. Depending on the length of time the instrument data were bad, the calculated values were estimated by linear interpolation. Linear interpolation was used for short time periods (up to 6 h) where it would be appropriate on the basis of similar meteorological conditions at the time. Bad calculated data based on bad instrument data for longer time periods were not estimated and left blank in the data set. For certain periods, usually at sunrise and sunset when Bowen ratio was near -1.0, calculated data were estimated by linear interpolation with less than 5% of the data interpreted in this way. Finally, all carbon dioxide and ET flux data were critically examined for unusual or unexplained values that were then linearly interpolated. Flagging every data value as good, bad, or estimated was not practical for a data set of this size.

5. Data Availability

[7] The meteorological and Bowen ratio data presented in Table 1 from the shrub and grass sites are available at http://www.tucson.ars.ag.gov/dap/ maintained by the U.S. Department of Agriculture Agricultural Research Service Southwest Watershed Research Center in Tucson, Arizona, United States. A detailed description of the data format, metadata, access information, licensing, and disclaimers is also available.

6. Examples of Data Use

[8] The data set has been used for a wide variety of investigations into watershed properties and functions. *Hogue et al.* [2005] evaluated Noah, a land surface model, at the grass and shrub sites. Their objective was to examine the transferability of parameters between the similar sites and evaluate the model performance with the variety of weather conditions that are seen in the area. Results indicated the Noah model was able to simulate sensible heat, ground heat, and soil temperature with a great deal of accuracy using optimized parameter sets. However, during the monsoon season significant latent heat flux errors were seen in the model simulation.

[9] Remote sensing data was used to calibrate an ecosystem model for semiarid perennial grasslands [*Nouvellon et al.*, 2001]. Meteorological data from the data set, simulated plant growth, and water budget data from the data set drove

the model. TM and ETM+ images gathered for 10 years were used to refine the model, spatially. It was found that their approach could provide spatial information about both vegetation and soil conditions to be used for grassland management. Other investigators have used the data set with remote sensing to expand the point data both temporally and spatially. Landsat imagery was used to detect temporal and spatial changes in grassland transpiration, using a water deficit index (WDI) [*Holifield et al.*, 2003]. The WDI was derived from Landsat imagery and correlated well with ET from the database.

[10] Rangelands account for about 40% of the world's land surface. In the world's carbon budget, about 20% of the carbon being released to the atmosphere is unaccounted for in all the sources and sinks [*Schimel*, 1995]. Since rangelands make up such a large amount of land surface they might sequester some of the unaccounted for carbon. Agricultural Research Service (ARS) scientists started the ARS Rangeland Carbon Flux Program using twelve western U.S. rangeland sites to evaluate rangelands as sinks or sources of carbon to the atmosphere [*Svejcar et al.*, 1997]. Our data set is from one of the sites in the program, now called the ARS Agriflux Project, which has been expanded to include agricultural lands. The overall results are showing that most sites are sinks in most years, but some are sources. This data set with high carbonate content soils is one of the sites found to be a source of carbon to the atmosphere [*Emmerich*, 2003].

[11] The tremendous size of the database itself requires a large input of labor and time to quality control the data. Also meteorological data, by its nature, has many stray and unexplained data values that must be evaluated. This data set in combination with others has been utilized to evaluate statistical protocols that can be used to quality control this type of data set and greatly reduce data processing costs [*Perez-Quezada et al.*, 2007]. Multivariate and time series statistical analysis methods were used to quality control the data. The methods were able to produce a concordance of 93% on the 20-min flux data between technician checked data and overall carbon flux differing by 1.7%.

[12] One of the key watershed functions that require evaluation is the separation of ET into its component parts of evaporation from the soil surface and transpiration of water through the plants (M. S. Moran et al., Partitioning evapotranspiration in semiarid grassland and shrubland ecosystems using time series of soil surface temperature, submitted to *Agricultural and Forest Meteorology*, 2007). Using the ET data at the shrub site and whole plant transpiration measured by heat balance sap flow methods, soil evaporation was separated by difference [*Scott et al.*, 2006]. Overall, it was found that the ratio of plant transpiration to ET was 58%, but during the months the plants were taking up carbon it was around 70%.

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W. E. Emmerich and C. L. Verdugo, Southwest Watershed Research Center, ARS, USDA, Tucson, AZ 85719, USA. (bill.emmerich@.ars.usda.gov)