Flux Files and Flags Documentation

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These tables include descriptions of the measurements reported in the flux files for the Niwot Ridge AmeriFlux ftp site. Table I is a list of the column names (parameters), units, sensor type and location, as well as a footnote describing other comments concerning that parameter (how it was calculated, corrections applied, etc.). Table II describes a series of flags which correspond to the flux data files. These are included to signify when data was available. The time tags for both tables are contained within the first five columns. The time tag signifies the beginning of the half-hour period for which measurement is relevant. Typical reasons for unavailable data are loss of line power at the site, sensor malfunction, or inclement weather leading water deposited on the sonic anemometer. These also include micrometeorlogical flags, such as when energy balance is violated, etc. The notes included in Table II also designate how substitute data was used to fill in gaps in our data.

Table 1: Flux Data Files

Parameter (Flux)	Column Number	Units	Sensor Type	Location (Height)	Footnote
Year	1				
Julian Day	2				
Hour of Day	3				
Minute	4				
Second	5				
CO_2 flux (F_{CO2})	6	$\mu mol\ m^{-2}\ s^{-1}$	Li-Cor 6262 and CSAT-3	21.5 m	1
CO_2 flux with a u* filter	7	$\mu mol\ m^{-2}\ s^{-1}$	Li-Cor 6262 and CSAT-3	21.5 m	1
CO_2 storage flux (S_{CO2})	8	$\mu mol\ m^{-2}\ s^{-1}$	Li-Cor 6251	0.5 - 21.5 m	1
Kinematic momentum flux	9	$m^2\ s^{-2}$	CSAT-3	21.5 m	2
Momentum flux	10	$kg\ m^{-1}\ s^{-2}$	CSAT-3	21.5 m	2

Table 1: Flux Data Files

Parameter (Flux)	Column Number	Units	Sensor Type	Location (Height)	Footnote
Sensible Heat flux (H)	11	W m^{-2}	CSAT-3	21.5 m	3
Latent Heat flux (LE)	12	W m^{-2}	CSAT-3 and Campbell KH20 or Li-Cor 6262	21.5 m	4
H_2O Vapor flux	13	mmol m^{-2} s^{-1}	CSAT-3 and Campbell KH20 or Li-Cor 6262	21.5 m	4
Soil Heat flux (G)	14	W m^{-2}	REBS HFT-1	10 cm below-ground	5
Sensible Heat Storage (S_H)	15	W m^{-2}	Vaisala HMP35-D	2, 8 and 21.5 m	6
Latent Heat Storage (S_{LE})	16	W m^{-2}	Vaisala HMP35-D	2, 8 and 21.5 m	6
Bole Heat Storage (S_B)	17	W m^{-2}	CSAT-3 and Campbell KH20 or Li-Cor 6262	3 and 7 cm within bole at breast height	7
Needle Heat Storage (S_N)	18	W m^{-2}	Vaisala HMP35-D	8 m	7

Footnotes to Table 1.

(1) The CO_2 flux is measured as :

$$F_{CO2} = (\overline{w'c'}) + \int_0^{z_m} \frac{\partial c}{\partial t} \partial z$$

where c denotes CO_2 density (µmol m^{-3}). The term $\overline{w'c'}$ denotes the eddy covariance flux measured at 21.5 m (~ 10 m above the canopy) where CO_2 is measured using a Li-Cor 6262 gas analyzer. The integral on the right describes the CO_2 storage term within the canopy and is measured using a Li-Cor 6251 gas analyzer and an automated profile system with six inlet heights ranging from 0.5 to 21.5 m. A detailed description of these instruments is given in Sensors.pdf. Lag times for the eddy covariance system due to transit time within the inlet tube were periodically calculated using cross-correlation of the w-wind axis with CO_2 (and/or H_2O vapor). The lag was found to be constant within 1-2 samples (t_{lag} ~ 1.6 s). Density corrections due to changes in water vapor concentrations were made according to Webb *et al*. (1980) Density corrections due to temperature were not necessary, as the gas was passed through a 1 m length of copper tubing to equilibrate temperature before entering the gas analyzer. Densities corrections were based either on the latent heat flux measured with the Kr hygrometer (KH20) or by using the H_2O channel of the Li-6262. No significant difference was observed depending on the sensor used for the H_2O density correction. Column 1 denotes the raw CO_2 flux time series. Column 2 denotes the same time series, but using a u* filter to replace fluxes during periods of high stability which can lead to an underestimate of the flux as has been done previously (Goulden, *et al*. 1996, Black *et al*., 1996). Typically these stable periods occur only at night. At values of u* < 0.2-0.25 m s^{-1}, CO_2 fluxes varied with u*. Above that threshold, night-time fluxes were independent of u*. For nocturnal periods with u* > 0.2 m s^{-1}, plots of CO_2 flux vs. soil temperature were fit to the equation :

$$F_{CO2} = Ae^{B \cdot T_s}$$

where T_s is soil temperature (^oC) (A and B are derived coefficients). For periods where u* < 0.2, this relationship was used to calculate the CO_2 flux in column 2. Filters were generated seasonally - typically twice a year using data from spring-summer (March-July) and summer-fall (July-November). Mid-winter substitutions were best described by the preceding fall models.

(2) The kinematic momentum flux was measured as the covariance between the u and w axes of the wind speed ($\overline{u'w'}$) measured by the sonic anemometer. Before calculation of the momentum flux (and all other fluxes), the wind coordinate system was rotated so as to force $\bar{w}$ and $\bar{v}$ to zero by the method described by Kaimal and Finnigan (1994). Beginning in the spring of 2002 (May, 2002) - the wind coordinate system was rotated using the planar fit method described by Wilczak et al., 2001). The momentum flux in column 5 is obtained by converting the kinematic momentum flux using the air density (kg m^{-3}) which is obtained from the measured barometric pressure and temperature.

(3) Sensible Heat flux was measured by the CSAT-3 sonic anemometer as the covariance between the w-axis wind speed and the sonic temperature ($\overline{w't_c'}$). The sonic temperature flux was converted to a real temperature flux using the correction descibed by Schotanus et al. (1983). It is then converted to W m^{-2} by using the heat capacity and density of the ambient air.

(4) Latent Heat flux was measured by the covariance of water vapor and the w-axis wind speed. Water vapor was measured in two completely independent methods : (1) a Campbell KH20 Kr hygrometer and (2) a Li-Cor 6262 gas analyzer. Agreement of H_2O vapor fluxes between the two sensors is generally within 15% or better. No lag time was applied to the Kr hygrometer data as the sensor is co-located with the sonic anemometer. Cross correlation between the Kr hygrometer and the w-axis time series indicate that only a slight lag of +/- 0.1 s (+/- 1 sample at 10 Hz) was necessary. The error in neglecting this lag is less than 2%. Lag times for the Li-6262 were measured by cross correlation as described in footnote #1 for CO_2. The lag time for H_2O was typi-

cally about 0.1 s (1 sample) longer than that for CO_2 (t_{lag} ~ 1.7 s). Corrections for O_2 absorptions were applied to the Kr hygrometer flux data as described in Campbell operating manual for their Eddy Correlation System. Density corrections due to sensible heat flux were also applied as described by Webb *et al.*, (1980) were applied to the KH20 data. No sensible heat corrections were necessary for the Li-6262 H_2O fluxes. Both measurements were converted from water vapor flux to latent heat (LE) using the latent heat of vaporization and the air density.

(5) Soil heat flux reported is the average of 10 different sensors (all REBS HFT-1). These were located in 5 different locations in groups of two. Locations were chosen to attempt to characterize the major soil environments. Examples of such are : open and dry (within a small clearing), (2) near the base of trees (shadowed and damp), etc.

(6) The sensible (S_H) and latent heat(S_{LE}) storage was measured by observing the change in the measured profile of temperature or relative humidity at three heights (z = 2, 8 and 21.5 m). The storage terms were calculated as

$$S_H + S_{LE} = \rho_a c_p \int_0^{z_m} \frac{\partial \bar{T}}{\partial t} \partial z + \frac{\rho_a c_p}{\gamma} \int_0^{z_m} \frac{\partial \bar{q}}{\partial t} \partial z$$

where ρ_a is the air density (kg m^{-3}), c_p is the air specific heat (kJ kg^{-1} $^oC^{-1}$), $\bar{T}$ is the average temperature (^oC), $\bar{q}$ is the average H_2O density (kg m^{-3}) and γ is the psychrometric constant. The temperature and relative humidity were measured by three Vaisala HMP35-D sensors contained in aspirated shields.

(7) Heat storage in the tree boles was measured by observing the change in temperature within 8 representative trees (all 3 species and at 2 depths). Heat storage in the needles was estimated by assuming that changes in air temperature at 8 m height was representative of the change in temperature within the needles. The following equations then describe the heat storage terms

$$S_B + S_N = \frac{S_d \rho_d c_p}{n} \sum_{i=1}^{n} V_i \frac{\Delta T_i}{\Delta t} + \frac{\rho_N c_{pN}}{1 - W_N} \left(\frac{\Delta T}{\Delta t} \right)$$

where S_d = stand density (stem m^{-2}), ρ_d = bole density (kg m^{-3}, measured from tree cores), c_p = bole heat capacity (J kg^{-1} K^{-1}, from H_2O content, $c_p\{H_2O\}$ and $c_p\{cellulose\}$), n = number of sampled boles, V_i = volume of sampled boles (m^{-3}, from harvesting relationship), ΔT_i = change in Temperature (^oC) over Δt = the time interval (1800 s), ρ_N = needle density (kg needle m^{-2} land area, from harvesting data), c_{pN} = needle heat capacity (J kg^{-1} K^{-1}, from H_2O content, $c_p\{H_2O\}$ and $c_p\{cellulose\}$), W_N = Needle H_2O content (%), ΔT = change in Temperature at 8m (^oC) over Δt = the time interval (1800 s).

Table 2: Flux Flags and Their Description

Flag Name (Parmeter)	Column Number	Value	Note(s)
Year	1		
Julian Day	2		
Hour of Day	3		
Minute	4		
Second	5		
CO_2 flux flag	6	1 == Data available 2 == 10-day average 3 == Spline fit 4 == Empirical fit 5 == Not available	1
CO_2 Storage flag	7	1 == Data available 2 == 10-day average 3 == Spline fit 4 == Not available	2
Momentum flux flag	8	1 == Data available 0 == C1 data	3
H flag	9	1 == Data available 2 == 10-day average 3 == Spline fit 4 == Empirical fit 5 == Not available	4
LE flag	10	1 == Data available 2 == 10-day average 3 == Spline fit 4 == Empirical fit 5 == Not available	5
LE flag #2	11	0 == Kr hyg. 1 == Li 6262 2 == No data	6
G flag	12	1 == Data available 2 == 10-day average 3 == Spline fit 4 == Not available	7

Table 2: Flux Flags and Their Description

Flag Name (Parmeter)	Column Number	Value	Note(s)
S_H flag	13	1 == Data available 0 == Not available	8
S_{LE} flag	14	1 == Data available 0 == Not available	8
Energy Balance flag	15	0 == Violation 1 == Satisfied 2 == Not available	9
Stationarity flag	16	0 == Violation 1 == Satisfied 2 == Not available	10
Integral Statistics	17	0 == Violation 1 == Satisfied 2 == Not available	10
S_B flag	18	1 == Data available 0 == Not available	8
S_N flag	19	1 == Data available 0 == Not available	8

Footnotes to Table 2 :

(1) Flag to denote when CO_2 flux data are available (columns 1 and 2 of the Flux files) and has been quality checked. The method of substitution for CO_2 flux data depends upon the number of missing values found in a 24 hour period. If the number of missing data is less than 3, a spline fit to remaining daily values is used for gap-filling. Otherwise, either a 10-day average or an empirical fit to the CO_2 flux is used. Empirical fits of CO_2 flux vs. PPFD as a function of air temperature were used (see AmeriFlux website - Gap-filling Strategies). Some data are then flagged as questionable and then looked at on a daily basis. Reasons for questioning of data at this point include : (1) actual manipulation of instrument (example - manual calibration of the gas analyzer) (2) Violation of either energy balance, stationarity or the integral statistics (see footnotes 9 and 10). (3) Either an erroneous or lack of measurement of latent heat flux which is necessary for density correction.

(2) Flag to denote when the CO_2 storage fluxes are available. Measurement of the CO_2 storage flux began on May 1, 1999. Prior to this time, a value of zero is used for this flux. Since this encompasses the wintertime when snowpack is present, the estimate of the storage flux being close to zero does not lead to large errors. The method of substitution for CO_2 storage fluxes

depends upon the number of missing values found in a 24 hour period. If the number of missing data is less than 3, a spline fit to remaining daily values is used for gap-filling. Otherwise, a 10-day average of the CO_2 storage flux is used.

(3) Flag denoting when momentum fluxes are available. Data are flagged as questionable or are rejected subject to violations of energy balance, stationarity or the integral statistics (see footnotes 9 and 10). Gap-filling of momentum flux data is accomplished by comparing monthly momentum fluxes to the wind speed. These data are fit with a polynomial expression :

$$Momentum = A \cdot ws^2 + B \cdot ws + C$$

where ws = wind speed (m s^{-1}). This relationship and the wind speed measured at the nearby C1 met station (see Climate.pdf for its description) was used to replace missing data.

(4) Flag denoting when sensible heat fluxes are available. Data are flagged as questionable or are rejected subject to violations of energy balance, stationarity or the integral statistics (see footnotes 9 and 10). Gap-filling is similar to that for CO_2 fluxes, using either a daily spline fit for small gaps (1 1/2 hour) and either a 10-day average or an empirical fit based on net radiation for longer gaps.

(5) Flag denoting when latent heat fluxes are available. Data are flagged as questionable or are rejected subject to violations of energy balance, stationarity or the integral statistics (see footnotes 9 and 10). Gap-filling is similar to that for CO_2 fluxes, using either a daily spline fit for small gaps (1 1/2 hour) and either a 10-day average or an empirical fit based on net radiation for longer gaps..

(6) Flag denoting which sensor was used to calculate the LE flux. The default value is the KH20 Kr hygrometer. However, during periods when it is unavailable (optics become wet, sensor malfunction), the Li-6262 fluxes are used.

(7) Flag denoting when latent heat fluxes are available. Data is available after July 1, 1999. Gap-filling is similar to that for CO2 fluxes, using either a daily spline fit for small gaps (1 1/2 hour) and a 10-day average for longer gaps.

(8) Flags denoting when storage components of sensible heat, latent heat, bole and needle storage are available. Currently sensible and latent heat storage are reported beginning on May 1, 1999. Bole and Needle Storage reports begin on July 1, 1999. Earlier data will be added in the future. Currently there is no substitution of these parameters when data is missing and during these periods, the storage terms are assumed to be zero. These are typically small and this assumption does not lead to significantly large errors in energy balance calculations. Substitution using a weekly average will likely be incorporated at a future date.

(9) Energy Balance flag is defined as $0.65 < EB < 1.20$ where EB is defined as :

$$EB = \frac{H + LE}{R_{net} - G - S_H - S_{LE}}$$

where H = Sensible heat flux, LE = Latent heat flux, Rnet = Net radiation, G = Soil heat flux, S_H = sensible heat storage and S_{LE} = latent heat storage. Note that other storage have been left off (such as storage in the boles, needles and the soil above the heat flux sensors); however, they are expected to be small and will be added at a later date.

(10) Flags for stationarity and Integral Statistics as described by Foken and Wichura (1996). Stationarity is assumed if : $0.75 < w't'(5) / w't'(30) < 1.25$ where $w't'(5)$ is the average value of the 5 minute covariances of w and temperature within the half-hour period and $w't'(30)$ is the 30 minute covariance of w and temperature. The integral statistics are defined as :
Currently, only when both of these tests are violated is the data rejected and substituted for accordingly. If only one of these tests is violated, it should be looked upon as questionable.

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