**Protocol for Computation of Surface Boundary Layer
Parameters used to determine Soil Moisture Flux from
Meteorological Data Collected at LLNL, 1992-93.**

Frank Gouveia

March 1993

MASTER

gh

**Protocol for Computation of Surface Boundary Layer
Parameters used to determine Soil Moisture Flux from
Meteorological Data Collected at LLNL, 1992-93.**

1. Introduction

Starting May 1992, meteorological data is continuously collected for Environmental Restoration Division (ERD) at the LLNL weather-tower site. Mounted on a 2-meter mast are sensors for air temperature, wind speed and direction, relative humidity, net radiation flux, and ground heat flux. Table 1 lists the height of the sensors and the sensor accuracies.

Table 1. List of sensors on the ERD mast.

Parameter	Height above surface (m)	Precision
Air Temperature	1.98, 1.09, 0.61, 0.25	0.1°C
Wind Speed	2.44, 0.97	0.1 m/s
Wind Direction	2.08	5°
Humidity	1.96, 0.71	5%
Net Radiation	1.28	10 w/m ²
Ground Heat Flux	1 cm below surface	10 w/m ²

These sensors are sampled every second and 15-minute averages are saved by the data logger for retrieval. Average and standard deviation (σ_s) of wind direction are computed by the Campbell logger (Campbell Scientific, Model CR-10) using polar coordinates as described in Yamartino (1984).

This report describes the reduction of continuously monitored data from 15-minute averages to hourly averages. The bulk of this report is dedicated to describing the computation of parameters that characterize the surface boundary layer. The ultimate goal is to provide estimates of the amount of evaporation of water from the surface.

2. Fifteen-minute Data

The raw data are transmitted from the Campbell logger to a PC via modem. These ASCII data are saved in files named jjj_Eyy.PRN, where jjj is the Julian date and yy is the year. For example, 140_E92.PRN contains logger data from the ERD mast starting on Julian day 140. The program RDCS has been written to convert the raw data to tables featuring one row for each 15-minute

time step. The 15-minute data is stored in files named `jjj_Eyy.DAT`. It is convenient to edit these files to include data from exactly 10 days per file. The Campbell logger labels data with the time from the end of the averaging period. RDCS subtracts 15 minutes to follow the convention that data is associated with the time of the beginning of the averaging period. Appendix A contains the initialization files used by RDCS to translate the raw data to 15-minute data tables.

3. Hourly Data

Hourly averages of the 15-minute data are computed according to methods in EPA-450/4-87-103, Chapter 6. Program HOUR has been written to compute the averages to files named `jjj_Eyy.HLY`. All parameters are smoothed with a simple arithmetic mean except wind direction, σ_θ , maximum, and minimum. The average horizontal wind direction is computed by resolving the polar coordinates of the average orthogonal components. Average standard deviations are computed by root-mean-squared algorithm. Hourly maximum and minimum values are selected from the available 15-minute maximums and minimums, respectively. Appendix B contains initialization files used by HOUR to compute hourly averages.

Time series plots are created for each 10-day period. An example of one set of plots is presented in Appendix C.

4. Estimate Displacement Height

Displacement height (d_0) can be estimated with a measuring tape or meter stick. The displacement height is estimated to be 70% of the mean top of the vegetation. The method used for this estimate is described as follows. Transects are established extending 30 m from the mast location in the downwind direction (south to west for LLNL). While holding the meter stick vertically against the ground, estimate the mean height of the vegetation (h) within a horizontal circle of radius 0.5 m. Repeat several times at 1 m intervals along the transect. Compute a mean and standard deviation of $d_0 = 0.7h$.

5. Surface Roughness

Surface roughness (z_0) is estimated from the 15-minute data during near-neutral conditions. Periods of high winds ($u > 3$ m/s) are selected to assure neutral conditions and speeds greater than the instrument threshold. Surface

roughness is calculated by extrapolating the wind speed against log of height to $u=0$,

$$\text{Ln}(z_0) = \text{Ln}(z_2 - d_0) - \frac{u_2}{u_2 - u_1} \cdot \text{Ln}\left(\frac{z_1 - d_0}{z_2 - d_0}\right), \quad (1)$$

where u_1 is the horizontal wind speed at height z_1 .

A graph of u versus $\text{Ln}(z_0)$ is created for each set of data. The average $\text{Ln}(z_0)$ is computed. Care is taken to select data when the mean flow is unobstructed by the mast.

6. Absolute Humidity

Sensors on the ERD mast measure temperature (T) in $^{\circ}\text{C}$ with precision of ± 0.1 $^{\circ}\text{C}$ and relative humidity (RH) with precision of 1% except near saturation. These quantities are combined in the following equation to yield absolute humidity (ρ_v) in gm/m^3 ,

$$\rho_v = \frac{e_s(T) \cdot RH / 100}{R_v \cdot (T + 273.)}, \quad (2)$$

where e_s is the saturation vapor pressure in millibars,

$$e_s = 6.108 \cdot \exp[17.42 \cdot T / (T + 239.7)], \quad (3)$$

and R_v is the gas constant,

$$R_v = 4.615 \times 10^{-3} \frac{\text{mb} \cdot \text{m}^3}{\text{gm} \cdot \text{deg}}. \quad (4)$$

These above equations are valid with atmospheric water in the liquid phase, therefore temperatures must be above 0°C .

7. Scaling Parameters

It has been well verified (Randerson 1984, page 160) that in the surface layer the profiles of mean wind speed u , mean temperature T , and mean absolute humidity q , are all logarithmic with height,

$$u_* = k \cdot u_z / \text{Ln}[(z - d_0)/z_0], \quad (5)$$

$$T_* = k \cdot \frac{dT}{d[\text{Ln}(z - d_0)]}, \quad (6)$$

$$q_* = k \cdot \frac{d\rho_v}{d[\text{Ln}(z - d_0)]} = k \cdot \frac{\rho_{v2} - \rho_{v1}}{\text{Ln}\left(\frac{z_2 - d_0}{z_1 - d_0}\right)}, \quad (7)$$

where u_* is the friction velocity, k is the Karman constant ($k=0.4$), u_z is the mean wind speed at height z . The temperature scale, T_* , is calculated by the

least-squares fit line of the four temperature measurements against the natural log of height. The atmospheric moisture scale, q^* , is calculated through a simple difference of the absolute humidity from the two levels.

8. Richardson Number and Diabatic Function

Atmospheric stability is commonly expressed as the Richardson number (Ri) which is the ratio of bouyancy to inertial forces (Randerson 1984, page 164). The following equation is a convenient form,

$$Ri = \frac{9.8}{(T + 273.15)} \cdot \frac{(T./k \cdot z_m + \Gamma)}{(u./k \cdot z_m)^2} \quad (8)$$

where $z_m = 2 - d_0$ is the height in meters of the Ri measurement, and Γ is dry adiabatic lapse rate ($0.01^\circ\text{C}/\text{m}$).

Functional forms of the diabatic function (ϕ) are as follows,

$$\phi = (1 - \gamma \cdot Ri)^{-1/2}, \quad (9)$$

for unstable atmosphere ($Ri < 0$) (Dyer and Hicks 1970). Typical value for γ is 16, but may be site dependent. The determination of γ for our site is described in section 10.

For the stable case ($Ri \geq 0$) Webb (1970) presented this relationship,

$$\phi = 1 + \alpha \cdot Ri, \quad (10)$$

where the constant α is found to be 5.

9. Sensible and Latent Heat Fluxes

Sensible heat flux (H) is found using this form for elevations near sea level,

$$H = \rho \cdot c_p \cdot \frac{u. \cdot T.}{\phi} = 1200 \cdot \frac{u. \cdot T.}{\phi}, \quad (11)$$

where ρ is the density of air, c_p is the heat capacity, and ϕ is the diabatic correction. H has units of watts/ m^2 .

Evapotranspiration is measured as the latent heat flux (LE) and is considered the residual of the heat balance equation,

$$LE = -(R + G + H), \quad (12)$$

where R is net radiation and G is ground heat flux.

10. Determination of γ

Several times during the year eddy-correlation measurements are taken through the course of a typical day with a Campbell heat flux unit (vertical component sonic anemometer coupled with a fine-wire thermocouple, Campbell

Scientific Model CA-27, with data logger, Campbell Scientific Model CR-21X). Many measurements are taken but here we will only consider the correlation of temperature and vertical wind speed, $(\overline{w'T'})$,

$$H = \rho \cdot c_p \cdot \overline{w'T'}. \quad (13)$$

Comparisons can be made of the diabatic function as calculated by instruments on the ERD mast and the eddy-correlation mast. Richardson number is computed by Eq. 8 and plotted against a family of curves of ϕ with appropriate values of γ . Setting Eq. 11 equal to Eq. 13 and solving for ϕ ,

$$\phi = \frac{u_* \cdot T_*}{\overline{w'T'}}. \quad (14)$$

Such a comparison has been made using data taken on 21 May 1992, and Figure 1 shows ϕ values computed by Equations 9 and 14. The value of ϕ during very unstable conditions ($-Ri > 0.1$) should be considered. From this figure a value of 8 has been chosen for γ . The value of γ may change through the year or when there is a change in the characteristics of the surface.

Figure 1. Richardson Number versus measured ϕ (Eq. 14) for the 21 May 1992 eddy correlation experiment. The family of curves represent three values of γ in Eq. 9.

11. Compilation of Bowen Ratio

Daily total energy for each component of the heat budget will be compiled and the Bowen ratio (B) computed,

$$B = \frac{H}{LE}. \quad (15)$$

An example of this data for three days in May follows as Table 2.

12. Combined Data, Quality Assurance and Expected Errors

Simultaneous meteorological measurements were collected near the LLNL weather tower on the Micromet Mast. These measurements were taken as part of the freeze-warning system for LLNL and started in December of 1991. When data from the ERD and Micromet masts are combined, the resulting data compares very well with eddy-correlation measurements. Table 3 shows integrated values of all measured and computed heat-flux quantities during such a comparison. Values of net radiation (Net Rad), ground heat flux (Ground), sensible heat flux (Sensible), and latent heat flux (Latent) are integrated for the daylight hours of the experiment. The eddy-correlation data includes direct measurement of sensible heat through a sonic anemometer. The combined data is a compilation of the ERD and Micromet data sets. For each 15-minute period, net radiation and ground flux are averaged. T^* is computed by least-squared fit of eight temperatures. u^* is a simple average of ERD and Micromet data.

Measurement of heat flux from the temporary mast (noted in Table 3 as Eddy) are compared to heat flux inferred by permanent mast data (noted as Combined). Standard deviations and percent error provide a measure of the expected error of measuring surface heat flux.

Table 2. Daily total energy (watts/m²) for components of the heat budget and bowen ratio as computed from the ERD Mast.

Date	R	G	H	LE	B
29 May '92	4401	-48	-2140	-2213	0.967
30 May '92	4414	-50	-2060	-2304	0.894
31 May '92	4238	-29	-1935	-2275	0.851

Table 3. Results from comparing eddy-correlation data and meteorological data from ERD and Micromet masts during experiment on 3 November 1992.

3 November '92	Julian 308		Integrate from 0800 to 1600		
Data Set	Net Rad	Ground	Sensible	Latent	Bowen Ratio
Eddy	1829	4	-1036	-796	1.26
Combined $\gamma=8$	1916	-77	-1001	-838	1.19
Error σ	43.6	40.2	17.4	20.8	
Error %	2.3	109.7	1.7	2.5	3.1

14. Convert Latent Heat to Equivalent Rainfall

Flux of latent heat can be converted to equivalent rainfall in millimeters of water per day by multiplying by the heat of evaporation and a dimension factor.

$$L \frac{\text{watt} \cdot \text{hour}}{\text{meter}^2 \cdot \text{day}} = L \frac{w \cdot h}{\text{m}^2 \cdot \text{d}} \cdot \frac{\text{m}^2}{698w} \cdot \frac{\text{cal}}{\text{cm}^2 \cdot \text{min}} \cdot \frac{60 \text{ min}}{\text{h}} \cdot \frac{\text{gm}}{585 \text{ cal}} \cdot \frac{\text{cm}^3}{\text{gm}} \cdot \frac{10 \text{ mm}}{\text{cm}} =$$

$$L \frac{w \cdot h}{\text{m}^2 \cdot \text{d}} \cdot 1.47 \times 10^{-3} \frac{\text{m}^2}{w \cdot h} \text{ mm} \Rightarrow \frac{\text{mm H}_2\text{O}}{\text{day}}$$

13. References

- Dyer, A.J. and B.B. Hicks (1970), "Flux-gradient relationships in the constant flux layer," *Quart. J. Royal Met. Soc.* **96**, 715-721.
- EPA-450/4-87-103 (1987), *On-site Meteorological Program Guidance for Regulatory Modeling Applications*, United States Environmental Protection Agency, Research Triangle Park, NC.
- Randerson, D., editor (1984), *Atmospheric Science and Power Production*, National Technical Information Service, Springfield, VA, DOE/TIC-27601.
- Yamartino, R.J. (1984), "A comparison of several "single-pass" estimators of the standard deviation of wind direction," *J. Climate Appl. Meteor.* **23**, 1362-1366.
- Webb, E.K. (1970), "Profile relationships: the log-linear range and extension to strong stability," *Quart. J. Royal Met. Soc.* **96**, 67-90.

Appendix A -- RDCS initialization files

The following is the initialization file valid from 21 to 27 May 1992.

Data fields for Campbell Scientific Data Logger

Site - ERD Tower 15-min, LLNL

15, 15-minute Average

212, 4, Tag and Field of Year

2, Field of Julian Date

3, Field of HrMn

Tag,Field,Order,	Label,	Format, Mult,Offset
212, 5, 1,	'Eatt',	'(F8.1)', 1, 0
212, 6, 2,	'T-Int',	'(F8.1)', 1, 0
218, 4, 17,	'NetRad',	'(F8.1)', -0.923, 0
218, 5, 18,	'GFlux',	'(F8.1)', 26.97, 0
221, 4, 9,	'T-RH 2m',	'(F8.2)', 1, 0
221, 5, 10,	'T-RH 1m',	'(F8.2)', 1, 0
221, 6, 11,	'RH 2m',	'(F8.2)', 1, 0
221, 7, 12,	'RH 1m',	'(F8.2)', 1, 0
224, 4, 4,	'StdWS2m',	'(F8.2)', 1, 0
224, 5, 5,	'MaxWS2m',	'(F8.2)', 1, 0
224, 6, 6,	'MinWS2m',	'(F8.2)', 1, 0
230, 4, 3,	'WS 2m',	'(F8.2)', 1, 0
230, 5, 7,	'WD 2m',	'(F8.0)', 1, 2
230, 6, 8,	'Sig.The',	'(F8.1)', 1, 0
233, 4, 13,	'Temp 2m',	'(F8.2)', 1, 0
233, 5, 14,	'Temp 1m',	'(F8.2)', 1, 0
233, 6, 15,	'Temp.6m',	'(F8.2)', 1, 0
233, 7, 16,	'Temp.25',	'(F8.2)', 1, 0

The following is the initialization file valid from 27 May to present.

Data fields for Campbell Scientific Data Logger

Site - ERD Tower 15-min, LLNL

15, 15-minute Average

212, 4, Tag and Field of Year

2, Field of Julian Date

3, Field of Hr Mn

Tag, Field, Order Label Format

212,	5,	1,	'Batt',	'(F8.1)',	1,	0
212,	6,	2,	'T-Int',	'(F8.1)',	1,	0
218,	4,	15,	'NetRad',	'(F8.1)',	-0.923,	0
218,	5,	16,	'GFlux',	'(F8.3)',	26.97,	0
221,	4,	7,	'T-RH 2m',	'(F8.2)',	1,	0
221,	5,	8,	'T-RH 1m',	'(F8.2)',	1,	0
221,	6,	9,	'RH 2m',	'(F8.2)',	1,	0
221,	7,	10,	'RH 1m',	'(F8.2)',	1,	0
224,	5,	3,	'WS 1m',	'(F8.2)',	1,	0
227,	4,	4,	'WS 2m',	'(F8.2)',	1,	0
227,	5,	5,	'WD 2m',	'(F8.0)',	1,	2
227,	6,	6,	'Sig.The',	'(F8.1)',	1,	0
230,	4,	11,	'Temp 2m',	'(F8.2)',	1,	0
230,	5,	12,	'Temp 1m',	'(F8.2)',	1,	0
230,	6,	13,	'Temp.6m',	'(F8.2)',	1,	0
230,	7,	14,	'Temp.25',	'(F8.2)',	1,	0

Appendix B -- HOUR initialization files

The following is the initialization file valid from 21 to 27 May 1992.

Initilization file for Program HOUR
21, Number of channels in input file
1, Date channel
2, Hour channel
3, Number of channels that don't get averaged
1, Ignore date
2, Ignore hour
3, Ignore time
1, Number of Wind Direction channels
10, WD 2 m
2, Number of Sigma Theta channels
7, SigThe 2 m
11, Std WS 2 m
0, Number of Rainfall channels
1, Number of Max channels
8, Max WS 2 m
1, Number of Min channels
9, Min WS 2 m

The following is the initialization file valid from 27 May to present.

Initilization file for Program HOUR

19, Number of channels in input file

1, Date channel

2, Hour channel

3, Number of channels that don't get averaged

1, Ignore date

2, Ignore hour

3, Ignore time

1, Number of Wind Direction channels

8, WD 2 m

1, Number of Sigma Theta channels

9, SigThe 2 m

0, Number of Rainfall channels

0, Number of Max channels

0, Number of Min channels

Appendix C

Examples of time series graphs made for every 10-day period.

END

DATE
FILMED
10/01/93