CHAPTER V. MICROMETEOROLOGICAL DATA COLLECTION

D. I. Stannard
Water Resources Division
U.S. Geological Survey
Denver, Colorado

W. P. Kustas
USDA-ARS
Beltsville, Maryland

K. J. Allwine
Pacific Northwest Laboratories
Atmospheric Sciences Department
Richland, Washington

D. E. Anderson
Water Resources Division
U.S. Geological Survey
Denver, Colorado

A. INTRODUCTION

This report summarizes the nature and scope of micrometeorological and related data that were collected at four sites during the Washita '92 experiment. This multidisciplinary experiment took place in the Little Washita river basin, near Chickasha, OK, from June 8-19, 1992. Micrometeorological measurements were made at four meteorological sites, designated MS001 through MS004 (fig. V1).

Measurement of energy fluxes between the terrestrial surface and the atmosphere was the major focus of this effort. Assuming advection is negligible, the fluxes are related by:

$$Q^* + G + H + LE = 0 \qquad (1)$$

where Q^* is net radiation, G is soil-heat flux, H is sensible-heat flux, and LE is latent-heat flux. L is the latent-heat of vaporization of water (roughly constant) and E is the evapotranspiration rate. Q^* and G were measured using thermopile devices, and the turbulent fluxes H and LE were measured using both the Bowen-ratio and eddy-correlation methods.

The Bowen-ratio method is based on the assumption that the eddy diffusivities for H and LE in the atmospheric surface layer are equal. The Bowen ratio, β, which is the ratio of H to LE, can then be measured as:

$$\beta = \gamma \Delta T / \Delta e \tag{2}$$

where γ is the psychrometric constant, ΔT is the temperature difference between two elevations above a plant canopy, and Δe is the vapor-pressure difference between the same two elevations. Combining equation 1 with the definition of β leads to:

$$LE = -(Q^* + G)/(1 + \beta) \tag{3}$$

H is then calculated from equation 1. Calculated values of LE and H are dependent on measurements of Q*, G, ΔT and Δe, and on the validity of the advection and eddy-diffusivity assumptions.

The eddy-correlation method uses high-frequency measurements of vapor density, ρ_v, air temperature, T, and vertical windspeed, w, to compute LE and H independently. Assuming that the mean vertical windspeed, $\overline{w}$, is zero, the fluxes are:

$$LE = L\,\overline{w'\rho_v'} \tag{4}$$

and

$$H = \rho\, C_p\, \overline{w'T'} \tag{5}$$

where ρ is air density, C_p is the specific heat capacity of air, primes denote deviations from mean values, and overbars denote mean values during a measurement period. The quantities $\overline{w'\rho_v'}$ and $\overline{w'T'}$ are covariances.

The source area of a flux measurement made in the atmospheric surface layer is the area of the terrestrial surface from which the measured flux originates. A source area is elliptical, with the major axis extending upwind of the sensor (Schmid and Oke, 1990). Typically the major axis is on the order of 100 times the sensor height. If the surface within the source area is homogeneous the measurement is representative of that surface type, and the measurement is said to have adequate fetch. Large-scale inhomogeneities within the source area complicate interpretation of the measurement.

In addition to the energy flux data, various standard weather data (air temperature, humidity, windspeed and direction, barometric pressure), and supplementary data (soil moisture, soil temperature, solar radiation, photosynthetically active radiation) were collected routinely. Flux of carbon dioxide to individual leaf surfaces was measured at MS002 during discrete intervals using a leaf-chamber method.

B. MEASUREMENTS AT MS001

MS001 was located in a winter-wheat field that had been partially grazed and then allowed to revegetate. A single species of weed dominated, and was interspersed with dead wheat plants. Total percent cover was estimated at 60 percent. Adequate fetch extended in all directions.

Bowen-ratio, eddy correlation, weather, and supplementary data were collected at MS001 from DOY (day of year) 163 to DOY 171. Q* was measured using a REBS (Radiation Energy Balance Systems[1]) Q6 net radiometer, deployed at 1.38 m above land surface. G was measured using a combination method. Three Peltier-cooler soil-heat-flux plates (Weaver and Campbell, 1985) were buried at 5 cm to measure G_d, the flux at depth. Three 4-junction averaging thermocouple probes were used to measure the change in temperature of the soil between the surface and the 5-cm depth. The heat-storage flux in the 5-cm thick layer is:

$$\Delta ST = \Delta T_s \cdot C \cdot D/t \qquad (6)$$

where ΔST is the flux, ΔT_s is the change in mean soil temperature during the measurement period, C is the volumetric heat capacity of the soil, D is the depth of the plate, and t is the length of the measurement period. The soil-heat flux, G, is the sum of G_d and ΔST. The value of C was determined from estimates of bulk density and soil moisture.

Temperature and vapor-pressure differences were measured using a psychrometer exchange mechanism (Stannard, 1985). Two WVU-7 psychrometers, made by Delta-T Devices, were deployed at heights of 0.84 m and 1.84 m above land surface. The psychrometers were scanned for 10 min, exchanged, and then were idle for 5 min, to equilibrate to the new temperatures. Measurements from two of these 15-min cycles were averaged to produce a 30-min Bowen ratio that was unaffected by sensor bias.

All sensors used in the Bowen-ratio calculations were scanned every 5 sec, and 15-min or 30-min means were recorded on a Campbell Scientific 21X data logger.

Eddy-correlation measurements were made using a Campbell Scientific CA27 sonic anemometer (with finewire thermocouple) to measure w and T, and a KH20 krypton hygrometer to measure ρ_v. These sensors were deployed 1.6 m above land surface and were occasionally reoriented to maintain undisturbed air flow past the sensors. The sensors were scanned 10 times per second and the covariances in

---

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

equations 4 and 5 were computed every 15 min. Two of these 15-min covariances were averaged and recorded on a Campbell Scientific 21X data logger every 30 min.

Air temperature and humidity were measured using a Campbell Scientific HMP35C probe deployed 1.55 m above land surface. Windspeed and direction were measured using an R.M. Young 03001-5 wind sentry, deployed 1.87 m above land surface. Solar radiation and photosynthetically active radiation (PAR) were measured using a Licor LI-200S pyranometer and a Licor LI-190S quantum sensor, respectively, both deployed 1.51 m above land surface. These sensors were scanned every 5 sec, and average values were recorded on the 21X logger every 30 min. Average soil temperature in the top 5 cm of soil (used to calculate ΔST) was measured and recorded once every 30 min. Soil cores were obtained daily using a Soilmoisture Equipment Corp. 200-A soil core sampler. These cores extended from the surface to a 6-cm depth, and were used to determine bulk density and moisture content.

C. MEASUREMENTS AT MS002

MS002 was located in native pasture, densely vegetated with a mixture of grasses and forbs. The field was bordered on the north and south by wooded creeks, flowing west to east, about 200 m apart. The stands of trees were about 10 m high and about 20 m wide. The sensors were deployed slightly north of the centerline of the field, and may have had inadequate fetch at times. The field was convex in the north-south direction, possibly causing non-zero values of $\overline{w}$ at times.

Bowen-ratio, eddy-correlation, weather, and supplementary data were collected at MS002 from DOY 161 to DOY 171. Measured parameters, sensor and data-logger models, scanning intervals, and recording times at MS002 were identical to those at MS001. Deployment heights were: net radiometer, 1.32 m; Bowen-ratio psychrometers, 1.12 m and 2.12 m; eddy-correlation sensors, 1.7 m; temperature-humidity probe, 1.31 m; wind sentry, 2.24 m; and radiation sensors, 1.41 m. Soil cores were obtained daily.

Measurements of carbon dioxide and water vapor exchange from individual grass leaves were made at selected locations at MS002 from DOY 165 through DOY 169. A Licor LI-6200 portable photosynthesis system outfitted with a 1/4 liter chamber and PAR sensor was utilized in these measurements. Measurement times were approximately 0900-1700 central daylight time (CDT). Computations of stomatal conductance, transpiration rates and leaf photosynthesis will be made from these measurements of the change in gaseous concentrations with time inside the closed chamber. The methodology and instrumentation are reported in Field and Mooney (1990).

D. MEASUREMENTS AT MS003

MS003 was located in a winter-wheat field that had been fully grazed, and then overtaken by weeds. Vegetation was dense, and included many species of grasses and forbs. A farmyard was located about 90 m to the north, possibly interfering with the fetch in that direction, but fetch in all other directions was adequate.

Bowen ratio, weather, and supplementary data were collected at MS003 from DOY 162 to DOY 171. Temperature and vapor-pressure differences were measured using a psychrometer exchange mechanism designed by REBS, after Fritschen and Simpson (1989). Equilibration times, scanning intervals, and recording times for the psychrometers were identical to those at MS001 and MS002. Psychrometer heights were 1.02 m and 2.02 m. Collection of psychrometric data was interrupted frequently from DOY 162 to DOY 164 because of instrument malfunction; performance improved after DOY 164. Net radiation, weather, and supplementary data collection at MS003 was identical to that at MS001 and MS002. Deployment heights were: net radiometer, 1.47 m; temperature-humidity probe, 1.26 m; wind sentry, 1.72 m; and radiation sensors, 1.50 m.

Eddy-correlation measurements at MS003 were made using a 3-axis Applied Technologies SWS-211/3V sonic anemometer and a Campbell Scientific KH20 krypton hygrometer, deployed 1.8 m above land surface. The sonic anemometer measured vertical windspeed, and two orthogonal components of wind in the horizontal plane. Sensors were scanned and raw data were recorded on a Zenith SupersPort 286 portable computer 10 times per second. Covariances and fluxes were not computed on line (as at MS001 and MS002); they will be computed after performing coordinate rotation. Therefore no results from the 3-axis system are available for presentation in this report. Because of the large rate of data production (1.8 megabytes per hour), the 3-axis system was operated intermittently. Between DOYs 162 and 171, nine runs were made, lasting between 6 and 12 hours each.

E. MEASUREMENTS AT MS004

MS004 was located near the southeast corner of a densely vegetated grassy pasture. Sensors were about 50 m to 60 m north and west of gravel roads lined with trees.

The instrumentation at MS004 was designed and built by REBS as a pilot installation for the U.S. Department of Energy's Atmospheric Radiation Measurements (ARM) program. Bowen-ratio, weather, and supplementary data were collected beginning on DOY 210 and are expected to continue for several years. No eddy-correlation data were collected at this site.

Q* was measured using a REBS Q6 net radiometer, deployed 2.3 m above land surface. Five REBS HFT-3 soil-heat-flux plates were buried at 5 cm to measure G_d, and five platinum resistance thermometer probes were buried to measure the change in soil temperature. Each probe measured the mean temperature between the surface and the 5-cm depth.

Temperature and vapor-pressure differences were measured with modified Vaisala HMP35A temperature-humidity probes, deployed 0.83 m and 1.83 m above land surface. The exchange mechanism, designed by REBS, exchanged sensor positions every 15 min, allowing 2 min for equilibration after each exchange. Measurements from two 15-min periods were averaged to produce a 30-min Bowen ratio.

Windspeed and direction were measured using a Met One 010B anemometer and 5470 wind vane, respectively, both deployed at 3.0 m above land surface. Atmospheric pressure was measured using a Met One 090C barometric pressure sensor, deployed at 1.21 m above land surface. Soil moisture was measured over the 2 to 5 cm depth interval, using five Soiltest MC300 soil moisture sensors. This value of soil moisture was used with an estimate of bulk density to compute C in equation 6. All sensors on the REBS installation (except the soil temperature probes) were scanned every 30 sec, and 30-min means were recorded on a Campbell Scientific CR10 data logger. Soil temperature probes were scanned only during the second half of each half hour, and means were recorded at the end of each half hour.

E. PRELIMINARY RESULTS

Time series of Q*, G, H, and LE are presented for DOY 170, a relatively sunny day near the end of the experiment. Rain had not occurred since the morning of DOY 161. Estimates of certain parameters used to calculate fluxes (e.g. air density, mean vapor pressure, soil moisture, bulk density) were programmed into the data loggers to produce real-time flux estimates onsite. The flux values presented here are the onsite estimates and are therefore subject to change. It is estimated that final flux values will change by less than 10 percent or 10 W m^{-2}, whichever is greater. The subscripts b and e will be used to distinguish between Bowen-ratio and eddy-correlation measurements of LE and H.

Measurements of LE_b and H_b at MS001 fluctuated significantly through the midday period, even though (especially before 1400 CDT) the curve of Q* was relatively smooth (fig. V1). Most of the fluctuation was caused by fluctuations in G, which were transferred to H and LE (eq. 3). Measurement of G at MS001 was complicated by the large spaces between individual plants. The movement of shadows cast by these plants (caused by the sun's procession from east to west) produced large spikes in the value of G, and therefore LE_b and H_b. In contrast, LE_e and H_e fluctuated much less, and were probably more representative of the true fluxes (fig. V2). Daily totals of the BR and EC measurements agreed fairly well, however (fig. V2).

The canopy at MS002 was much denser than at MS001. This produced slightly greater Q*, a smoother trace for G (and therefore for LE_b and H_b), smaller values of G and H_b, and a larger value of LE_b, than at MS001 (figs. V3 and V1). Although the BR and EC measurements of LE and H were better correlated at this site (fig. V4), daily totals of EC fluxes were of smaller magnitude than daily totals of BR fluxes, which may be related to the inadequate fetch and topography at MS002.

The canopy at MS003 was similar to that at MS002, although there were more weeds and fewer grasses at MS003. Q*, G, LE_b, and H_b also were extremely similar at these sites (figs. V3 and V5). At both sites G and H were of similar magnitude, and were minor components of the energy balance.

Although the grass canopy at MS004 was dense, Bowen ratio measurements there indicated that the surface partitioned more energy into H_b and less into LE_b (fig. V6) than at MS002 and MS003. Apparently the grass canopy at MS004 transpired less water than the mixed canopies at MS002 and MS003.

Average Bowen ratios were calculated for the period 1130 to 1530 CDT at each site (Table V1). This period was chosen to symmetrically span local solar noon--approximately 1330 CDT. The average Bowen ratio was calculated by dividing the total LE measured during the period into the total H measured during the period. Bowen ratios determined for the BR and EC methods agreed surprisingly well, both at MS001 and MS002. Bowen ratios at MS002 and MS003 were similar, and Bowen ratios at MS001 and MS004 were similar. While similar Bowen ratios at MS002 and MS003 can likely be attributed to similar canopies, similar Bowen ratios at MS001 and MS004 can not. The large amount of bare soil at MS001 extracted a greater G than at MS004. The remaining energy was then partitioned between LE and H similarly at both sites. Apparently the smaller percent cover at MS001 had an equivalent effect on the partitioning process to the vegetation type resistance at MS004.

G. REFERENCES

Field, C.B., and Mooney, H.A., 1990, Leaf chamber methods for measuring photosynthesis under field conditions: Remote Sensing Reviews, v. 5, no. 1, p. 117-139.

Fritschen, L.J., and Simpson, J.R., 1989, Surface energy and radiation balance systems: general description and improvements: J. Appl. Meteor., v. 28, no. 7, p. 680-689.

Schmid, H.P., and Oke, T.R., 1990, A model to estimate the source area contributing to turbulent exchange in the surface layer over patchy terrain: Quart. J. Roy. Meteor. Soc., v. 116, p. 965-988.

Stannard, D.I., 1985, Design and performance of a machine used in the calculation of Bowen ratios: National Water Well Association, Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, Denver, 1985, Proceedings, p. 143-157.

Weaver, H.L., and Campbell, G.S., 1985, Use of peltier coolers as soil heat flux transducers: Soil Sci. Soc. Am. J., v. 49, no. 4, p. 1065-1067.

Table V-1. Sensor deployment at MS001

Variable	Sensor make and model	Sensor height or depth (m)
Net radiation	REBS Q6	1.38
Deep soil-heat flux	Modified Peltier coolers (Weaver and Campbell, 1985)	-0.05
Heat-storage flux	Thermocouples	-0.006, -0.019, -0.031, -0,044
Air-temperature difference	Delta-T WVU-7	0.84, 1.84
Vapor-pressure difference	Delta-T WVU-7	0.84, 1.84
Fast-response vertical windspeed	Campbell Scientific CA27	1.6
Fast-response air temperature	Campbell Scientific CA27	1.6
Fast-response vapor density	Campbell Scientific KH20	1.6
Air temperature	Campbell Scientific HMP35C	1.55
Relative humidity	Campbell Scientific HMP35C	1.55
Windspeed	R.M. Young 03001-5	1.87
Wind direction	R.M. Young 03001-5	1.87
Solar radiation	Licor LI-200S	1.51
Photosythetically active radiation	Licor L1- 190S	1.51

Table V-2. Sensor deployment at MS002

Variable	Sensor make and model	Sensor height or depth (m)
Net radiation	REBS Q6	1.32
Deep soil-heat flux	Modified Peltier coolers (Weaver and Campbell, 1985)	-0.05
Heat-storage flux	Thermocouples	-0.006, -0.019, -0.031, -0,044
Air-temperature difference	Delta-T WVU-7	1.12, 2.12
Vapor-pressure difference	Delta-T WVU-7	1.12, 2.12
Fast-response vertical windspeed	Campbell Scientific CA27	1.7
Fast-response air temperature	Campbell Scientific CA27	1.7
Fast-response vapor density	Campbell Scientific KH20	1.7
Air temperature	Campbell Scientific HMP35C	1.31
Relative humidity	Campbell Scientific HMP35C	1.31
Windspeed	R.M. Young 03001-5	2.24
Wind direction	R.M. Young 03001-5	2.24
Solar radiation	Licor LI-200S	1.41
Photosythetically active radiation	Licor L1- 190S	1.41
Leaf photosynthesis	Licor LI-62000	0.2 to 0.6

Table V-3. Sensor deployment at MS003

Variable	Sensor make and model	Sensor height or depth (m)
Net radiation	REBS Q6	1.47
Deep soil-heat flux	Modified Peltier coolers (Weaver and Campbell, 1985)	-0.05
Heat-storage flux	Thermocouples	-0.006, -0.019, -0.031, -0,044
Air-temperature difference	REBS (Fritschen and Simpson, 1989)	1.02, 2.02
Vapor-pressure difference	REBS (Fritschen and Simpson, 1989)	1.02, 2.02
Fast-response windspeed (three components)	Applied Technologies SWS-21113V	1.8
Fast-response air temperature	Applied Technologies SWS-211/3V	1.8
Fast-response vapor density	Campbell Scientific KH20	1.8
Air temperature	Campbell Scientific HMP35C	1.26
Relative humidity	Campbell Scientific HMP35C	1.26
Windspeed	R.M. Young 03001-5	1.72
Wind direction	R.M. Young 03001-5	1.72
Solar radiation	Licor L1-200S	1.50
Photosythetically active radiation	Licor Ll-190S	1.50

Table V-4. Sensor deployment at MS004

Variable	Sensor make and model	Sensor height or depth (m)
Net radiation	REBS Q6	2.3
Deep soil-heat flux	REBS HFT-3	-0.05
Heat-storage flux	REBS STP-1	0 to -0.05
Air-temperature difference	modified Vaisala HMP35A	0.83, 1.83
Vapor-pressure difference	modified Vaisala HMP35A	0,83, 1.83
Air temperature	modified Vaisala HMP35A	0.83, 1.83
Relative humidity	modified Vaisala HMP35A	0.83, 1.83
Windspeed	Met One 010B	3.0
Wind direction	Met One 5470	3.0
Atmospheric pressure	Met One 090C	1.21
Soil moisture	Soiltest MC300	-0.02 to -0.05

Table V-5. Average Bowen ratios between 1 1 30 and 1530 on day of year 170
[BR, Bowen-ratio sensors; EC, eddy correlation sensors]

Site	Sensors	Bowen Ratio
MS001	BR	0.86
MS001	EC	0.67
MS002	BR	0.43
MS002	EC	0.32
MS003	BR	0.36
MS004	BR	0.62

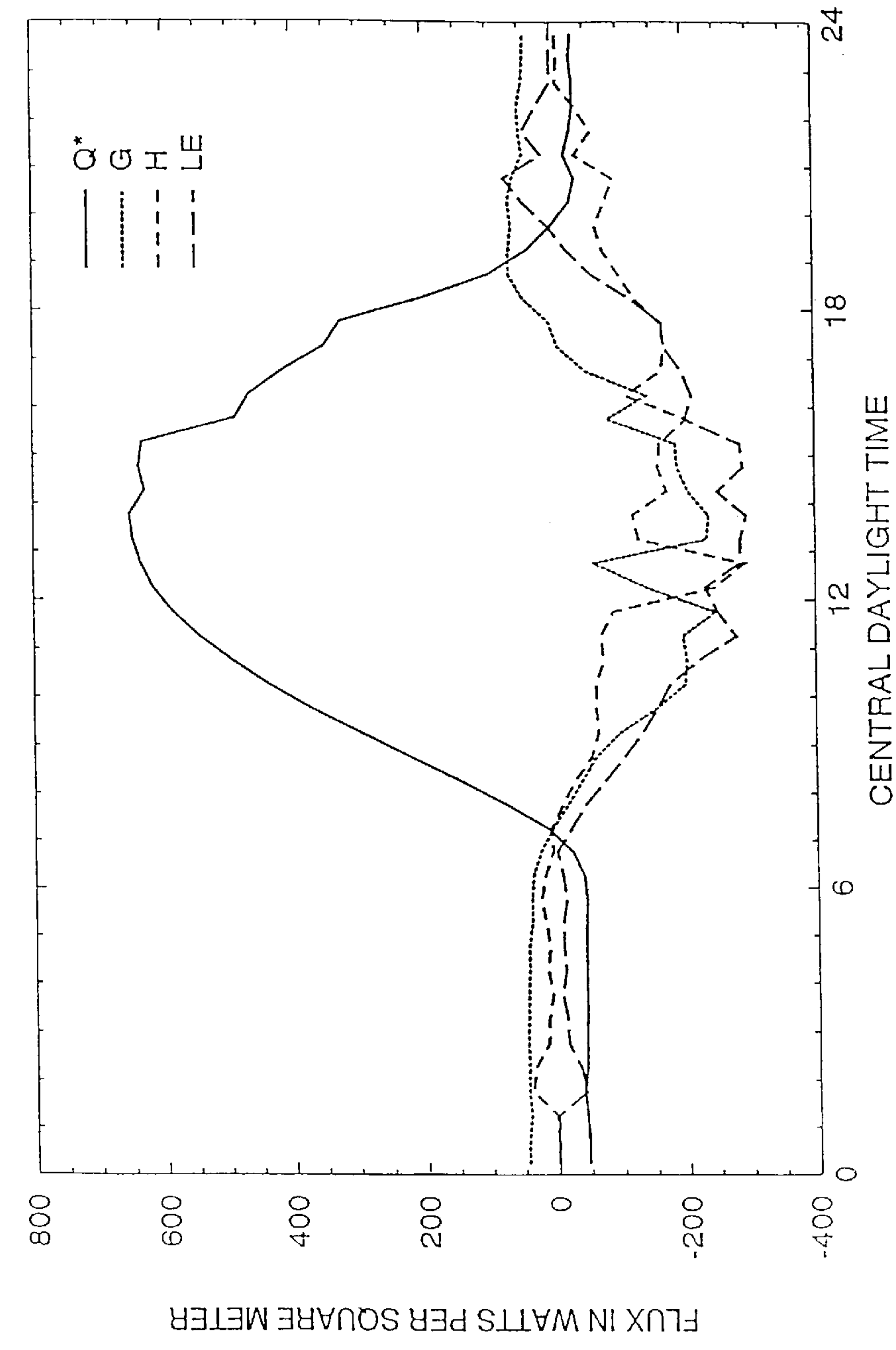

Figure V-1. Bowen-ratio fluxes at MS001 on June 18 (day 170)

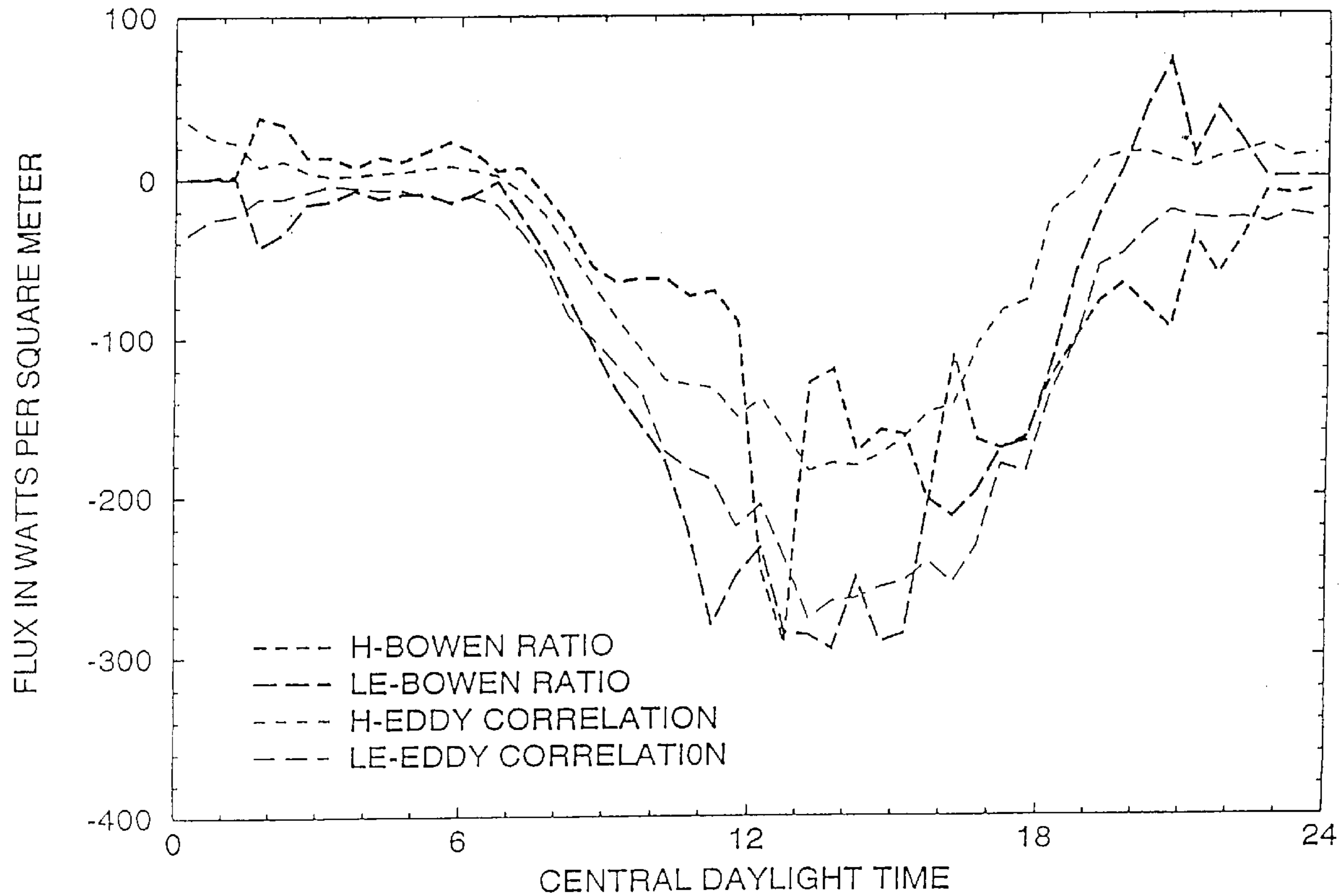

Figure V-2. Turbulent fluxes at MS001 on June 18 (day 170)

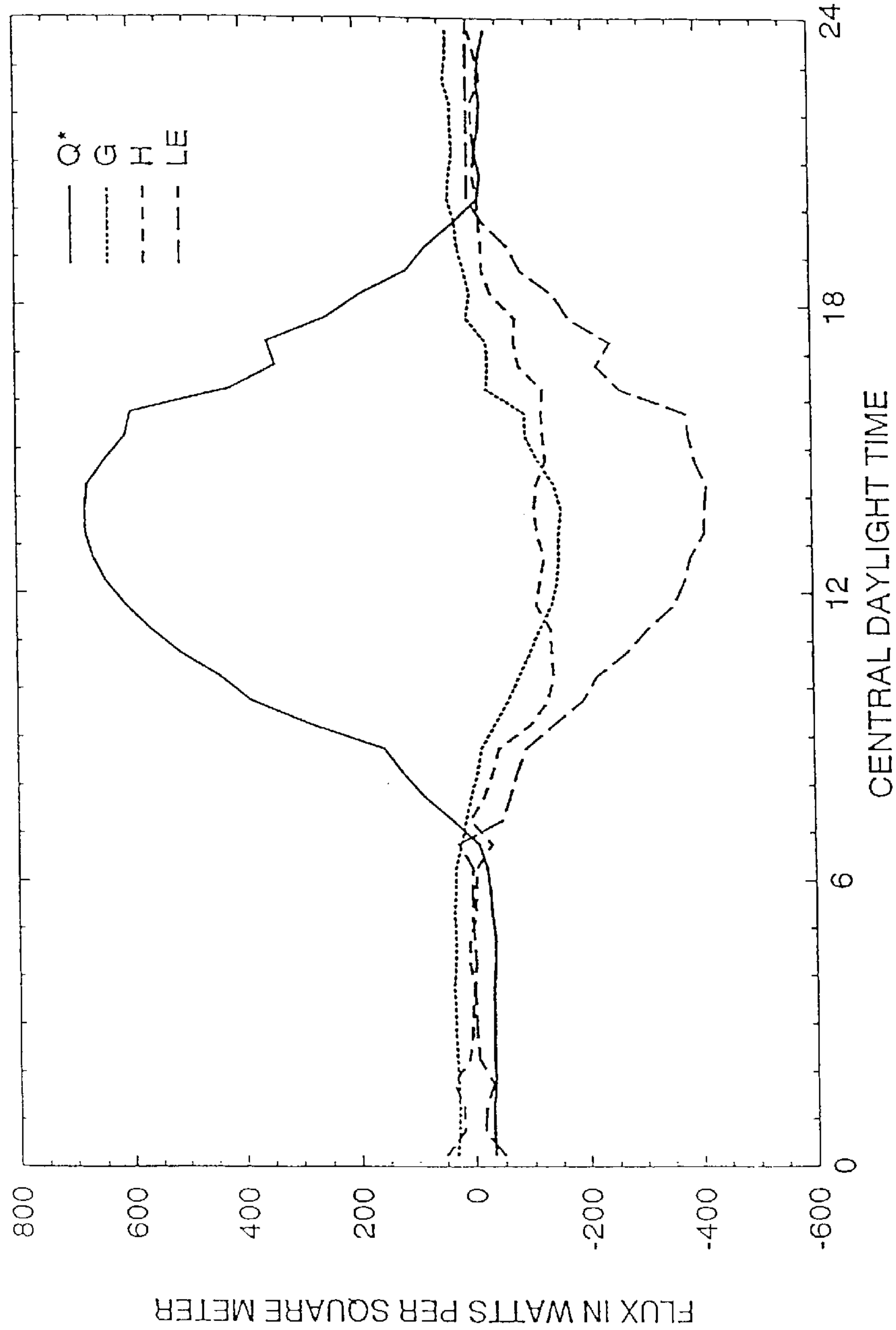

Figure V-3. Bowe ratio fluxes at MS002 on June 18 (day 170)

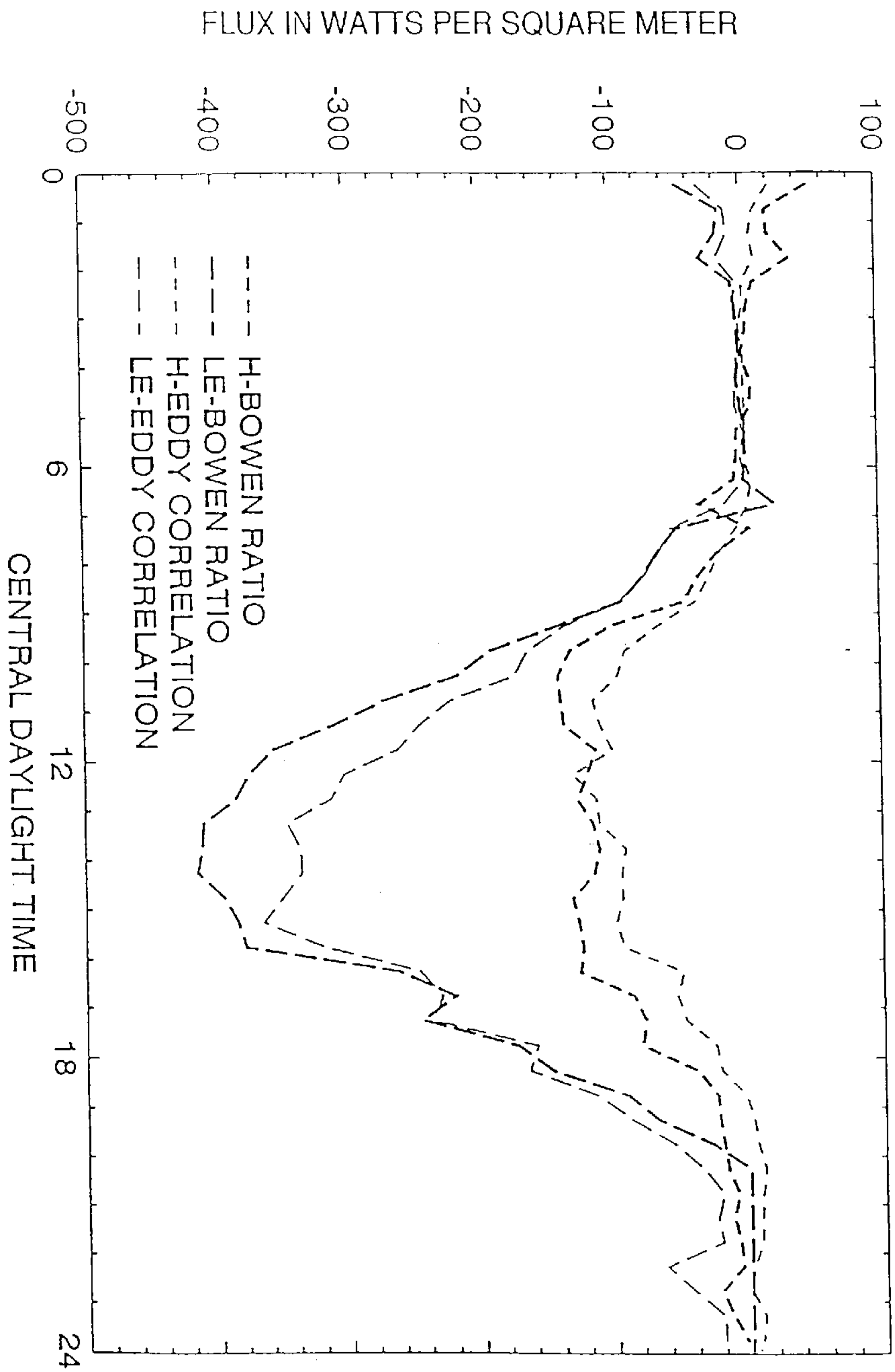

Figure V-4. Turbulent' xes at MS002 on June 18 (day 170)

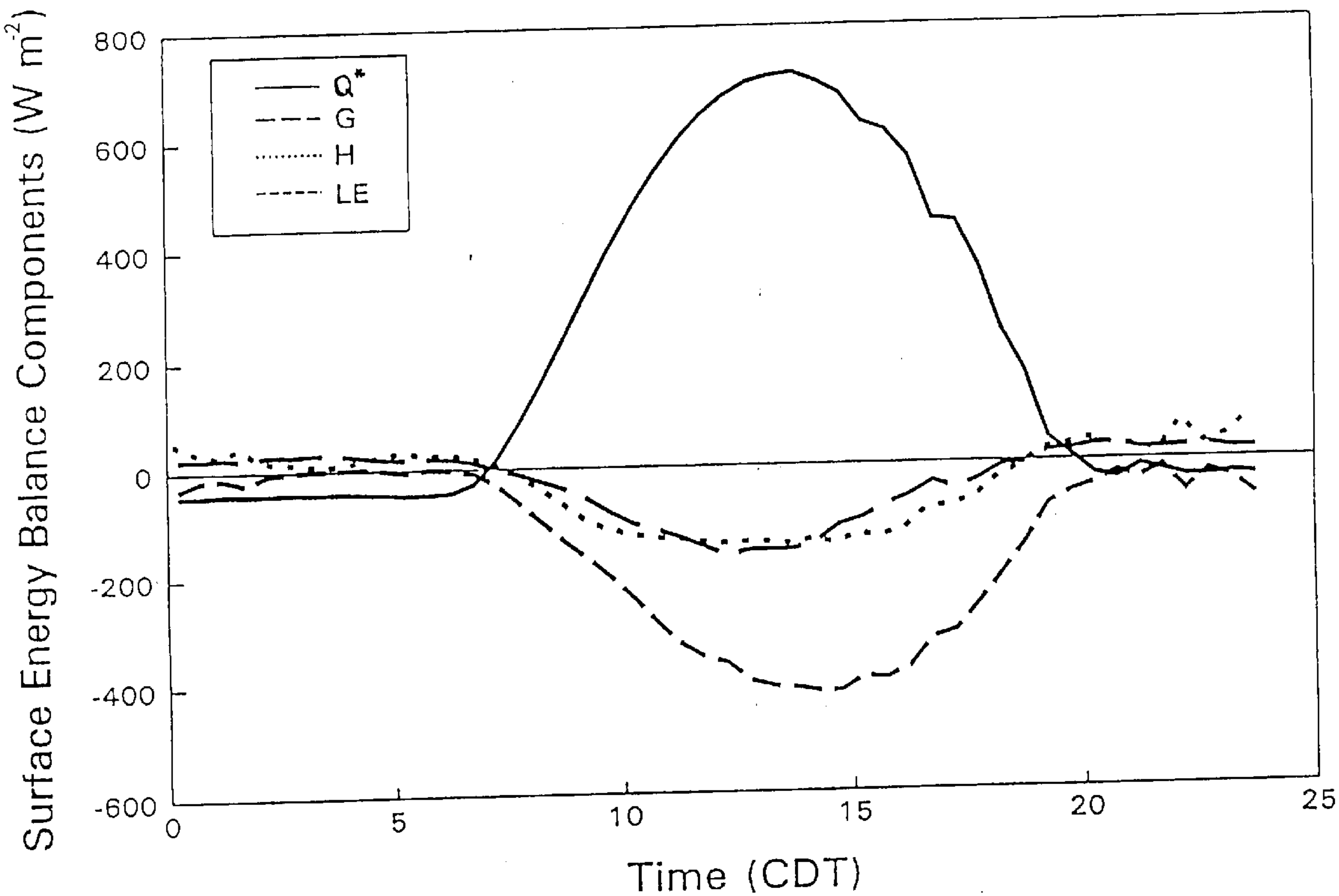

Figure V-5. Bowen-r[illegible] fluxes at MS003 on June 18 (day 170)

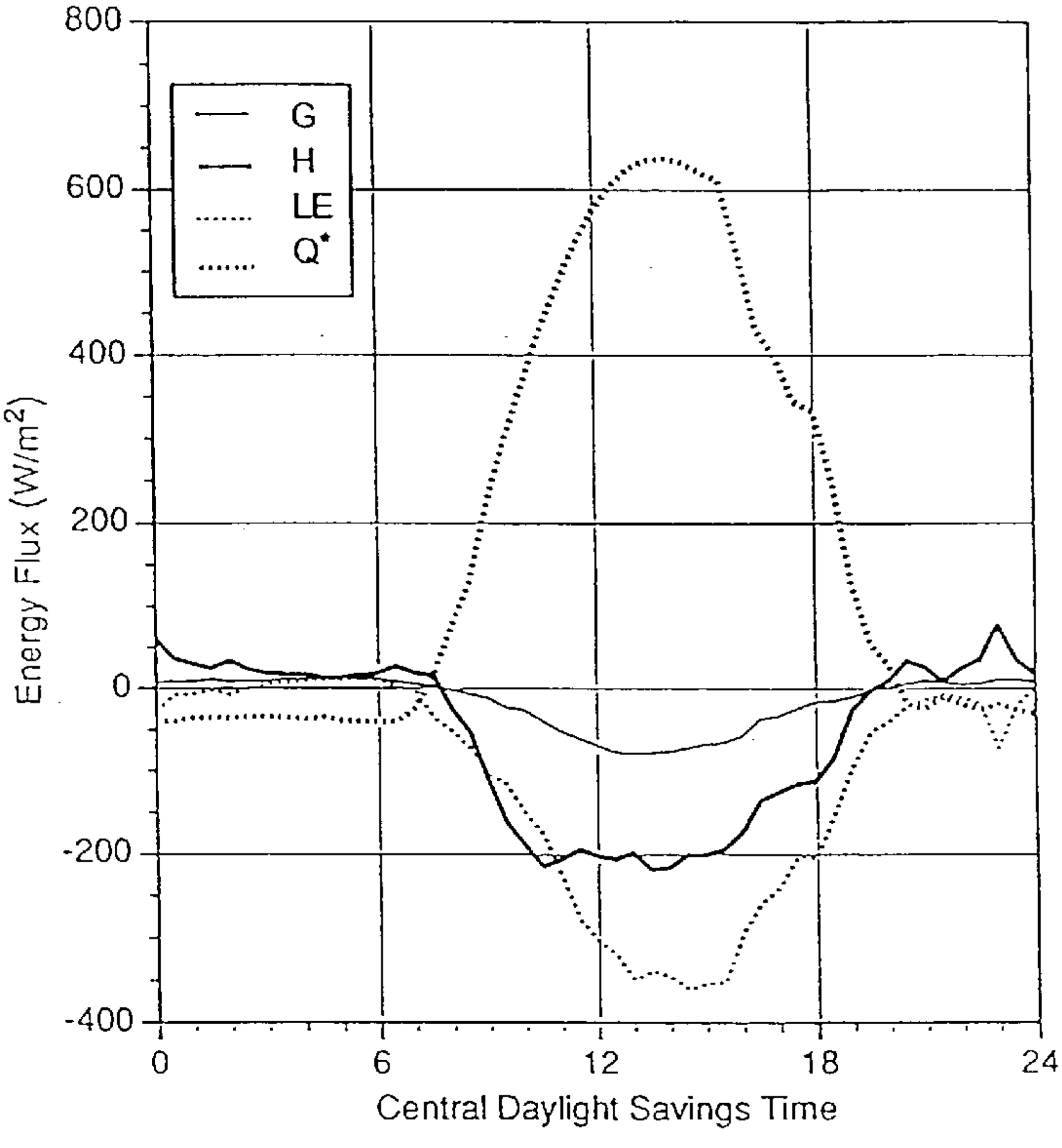

Figure V-6. Bowen-ratio fluxes at MS004 on June 18 (day 170)