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SURFACE HEAT FLUX DATA FROM ENERGY BALANCE BOWEN RATIO SYSTEMS

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1. INTRODUCTION

The 350 km by 400 km domain of the Atmospheric Radiation Measurement (ARM) Program's Clouds and Radiation Testbed (CART) site in the southern Great Plains (Stokes and Schwartz, 1994) is equipped with 10 energy balance Bowen ratio (EBBR) stations at grassland sites (Table 1). These stations routinely measure the net radiation (Rn), ground heat flux (G), and the temperature and humidity differences between nominal heights of 1.0 and 2.0 m (Fritschen and Simpson, 1989). The latter differences provide estimates of the geometric Bowen ratio (β), which are used to estimate the sensible and latent heat flux via the following formula:

$$Rn + G = -H(1 + \beta^{-1}) \quad (1)$$

Here β is assumed to be equal to the ratio of sensible heat flux (H) to the latent heat flux (λE), and the fluxes are assumed to be positive for energy transfer toward the surface. The EBBR stations operate continuously throughout the year and use an automatic exchange mechanism to switch the positions of the upper and lower sets of temperature and humidity sensors once every 15 min to minimize the effects of offsets and minor drifts in the all-weather sensors. The purpose of this paper is to address the problem that occurs when the value of β is near -1 and to demonstrate the effectiveness of the EBBR stations in collecting energy flux data at the CART site.

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2. OCCURRENCES OF β NEAR -1

Figure 1 shows a set of EBBR flux data collected over a 24-hr period. Only one "spike" in the data is evident because β is near -1, at 1915 hr CST, when the value of β was -1.07. Except for the annular solar eclipse that occurred at 1000-1300 hr, these data are fairly typical. On some days, no spikes occur, but 1-5 spikes are common, particularly near sunrise and sunset. If the measurements were devoid of error and in ideal conditions, spikes would be produced only when β was exactly -1, but small errors in the temperature and humidity measurements and the effects of nonstationary atmospheric conditions cannot be avoided. The EBBR data plotted in Fig. 2 show that many spikes occur over the course of one month. Some of the values are sufficiently large to produce significant sources of error in boundary layer analyses and even in long-term budgets of heat and moisture. Figure 2 indicates that incorrect estimates of sensible and latent heat fluxes occur mostly for values of β between approximately -0.75 and -1.5.

These spikes can be eliminated by editing, preferably by an automated procedure. One approach is to replace the estimates of H and λE with estimates calculated with a bulk aerodynamic (BA) approach when β is near -1. A BA method requires an estimate of friction velocity u_*, which can be obtained in iterative calculations based on measurements of wind speed and the temperature and humidity differences; estimates of aerodynamic surface roughness lengths and displacement heights are also necessary and can be roughly made if the vegetation height and general structure are known (e.g., Brutsaert, 1982). Figure 1 includes estimates made with the BA method used in this investigation; these estimates appear to be reliable throughout the day. Here, however, the recommendation for grasslands is to use the BA results in place of EBBR estimates only when

TABLE 1. Locations of the 10 EBBR stations and flux averages for August 1994. Sensible and latent heat estimates were made with the BA approach when $-1.5 < \beta < -0.75$.

Extended Facility (surface vegetation)	Latitude (deg N)	Longitude (deg W)	Altitude (m)	Rn (W m^{-2})	H (W m^{-2})	λE (W m^{-2})	u_* (cm s^{-1})
No. 4. Plevna, KS (ungrazed rangeland)	37.953	96.329	513	134	-74	-53	27
No. 7, Elk Falls, KS (pasture)	37.383	96.180	283	162	-49	-109	23
No. 8, Coldwater, KS (rangeland)	37.333	99.309	664	138	-95	-38	38
No. 9, Ashton, KS (pasture)	37.133	97.266	386	137	-1	-130	41
No. 12, Pawhuska, KS (tallgrass prairie)	36.841	96.427	331	158	-29	-123	26
No. 13, Central Facility, OK (pasture)	36.605	97.485	319	137	-17	-114	41
No. 15, Ringwood, OK (pasture)	36.431	98.284	418	146	-52	-86	40
No. 20, Meeker, OK (pasture)	35.564	96.988	309	156	-66	-85	33
No. 22, Cordell, OK (rangeland)	35.354	98.977	465	153	-94	-54	37
No. 26, Cement, OK (pasture)	34.957	98.076	400	147	-47	-94	32

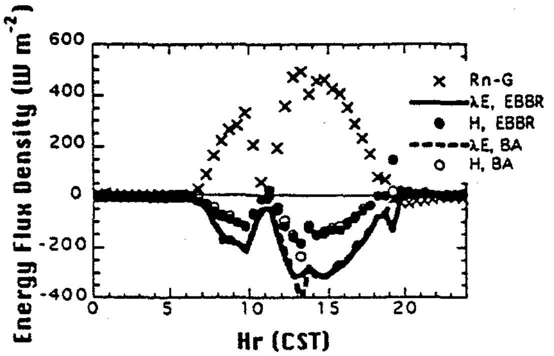

Figure 1. Estimates of energy fluxes made with the EBBR approach and a bulk aerodynamic (BA) method at the CART central facility on May 10, 1994.

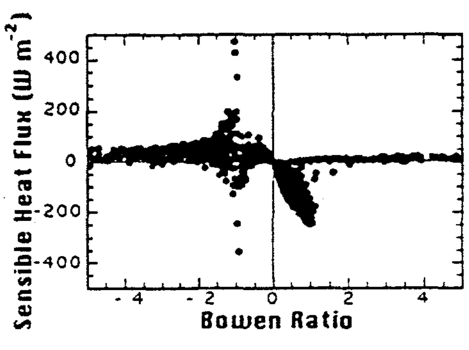

Figure 2. Half-hourly estimates of H versus β from the EBBR at the Cordell extended facility during August 1994.

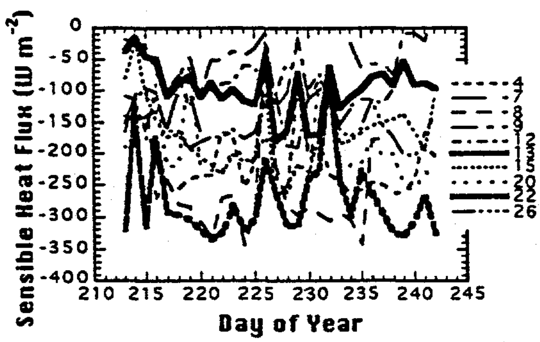

Figure 3. Daily averages of H between 0800 and 1600 hr at 10 EBBR stations during August 1994. Station numbers are defined in Table 1.

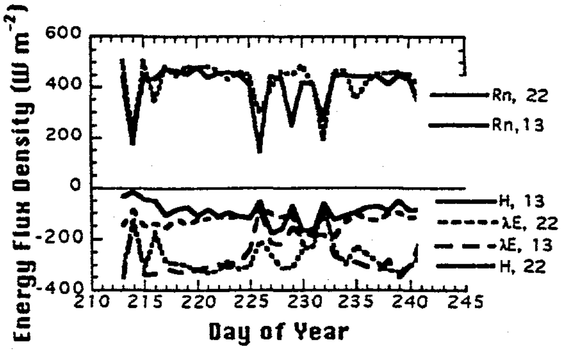

Figure 4. Daily averages of Rn, H, and λE between 0800 and 1600 hr during August 1994 at two EBBR stations selected for their large differences in H and λE values.

β is between -0.75 and -1.5 because the EBBR approach relies on fewer assumptions, particularly concerning the aerodynamic properties of the surface.

3. SPATIAL VARIATIONS OF H AND λE

Figures 3 and 4 illustrate strong spatial variability of H and λE across the CART domain. Areas on the west portions of the overall site had relatively large values of H and small values of λE, probably a consequence of rainfall variations. As Table 1 shows, the averages of fluxes for the entire month at all 10 EBBR stations indicate strong changes from site to site. For these flux data, the BA method was used to produce replacements for EBBR results when β was between -0.75 and -1.5 and to produce the estimates of u_* shown in Table 1. Because the surfaces were all grass covered and u_* did not vary greatly from site to site, the likely cause of the variations in H and λE was soil moisture differences as a result of rainfall and soil variability.

4. CONCLUSIONS

A bulk aerodynamic approach has been used successfully to obtain reliable estimates of H and λE from the EBBR stations when the value of β is near -1. After further testing, the BA approach can be implemented to provide a routine data product from the ARM CART site. Doing so will remove a significant source of error in air-surface exchange estimates used in developing parameterizations of atmospheric processes by various ARM scientists. A larger source of difficulty for large-scale models, however, might be the considerable variability in H and λE seen across the CART site. Obtaining a representative average of the fluxes for the entire CART site might require a more sophisticated approach than simple averaging.

The EBBR stations have proven to be fairly reliable in providing estimates of H and λE at various grassland locations at the ARM Program's CART site in the southern Great Plains. Each location is visited for maintenance and repair only once every two weeks. Possibly the most frequent difficulty has been interruptions in operation of the automatic exchange mechanism, especially when freezing rain or snow has occurred. A shortcoming of the implementation of the EBBR approach at the CART site is that the stations have been installed in untilled areas, to avoid re-installation during cultivation, harvest, and other agricultural practices. Several eddy correlation stations will be placed at the edges of tilled fields in 1995 to obtain measurements of H and λE above wheat fields and a few row crops.

5. ACKNOWLEDGMENTS

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