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Surface Energy Fluxes at Central Florida During the Convection and Precipitation Electrification Experiment

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Final Report

to

NASA/MSFC

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Dear Sirs:

Please find enclosed 2 copies of our final report to NASA grant NAG8-910.

Best wishes,

INTRODUCTION:

One of the objectives of CaPE is to better understanding the convective process in central and south Florida during the warm season. The energy and moisture exchanges between the surface and the atmosphere are closely related to this process. Some recent studies have shown that the surface energy balance plays an important role in the climatic fields (Shukla and Mintz, 1982; Sud and Smith, 1985; Sato et. al, 1989). Surface energy fluxes and related surface processes such as evapotranspiration and sensible heat transfer directly effect the temperature, humidity, cloud formation and precipitation. For example, mesoscale circulation around a discontinuity in vegetation type were shown to be stronger with wet soil than with dry soil using an evapotranspiration model (Pinty et. al, 1989). In order to better describe the processes in the atmosphere at various scales and improve our ability of modeling and predicting weather related events, it is crucial to understand the mechanism of surface energy transfer in relation to atmospheric events. Surface energy flux measurements are required to fully understand the interactions between the atmosphere and the surface.

An interdisciplinary science team carried out a field campaign for measuring surface fluxes in the vicinity of Cape Canaveral, Florida as part of the Convection and Precipitation/Electrification Experiment (CaPE). Scientists from the University of Georgia (UGA) participated the field campaign by operating two surface flux stations. To (1) assess the effect of surface heat and moisture transport and their variations on the initiation, maintenance and decay of mesoscale summertime convection; (2) explore the relationships between surface radiation, sensible and latent heat fluxes and convection storms; and (3) provide ground truth for evaluating, validating and initializing existing and new models simulating surface-atmosphere interaction. A series of parameters characterizing surface energy transfer and other properties (net radiation, soil heat flux, sensible and latent heat fluxes, temperature and humidity, precipitation, etc.) were measured continuously from 8 July to 18 August, 1991. Other surface parameters such as soil moisture, surface reflectance and light interception were also measured on selected days. This report summarize the data collected by UGA during the experiment.

MATERIAL AND METHOD

SITE DESCRIPTION:

The two sites operated by University of Georgia were both located west of I-94. The north site -- site UGA North (Latitude 28.6150°N, Longitude 80.9572°W) was co-located with KSC (Kennedy Space Center) wind tower site 1612. The site was primarily covered by grass with a few trees located in the vicinity. The site was grazed; however, the cattle were not in the field during the latter part of the experiment. The canopy height was about 40 cm in early July (beginning of the experiment) to a more dense cover of 87 cm in middle August (end of the experiment). The surface had a thin layer of green moss at this site probably due to the wetness of the surface soil. During the experiment, the soil at this site was usually saturated and was frequently covered with water. Soil moisture of the top 5 cm was normally 40% (g/g) or more. Site UGA south (28.5269°N, 81.0092°W) southwest of Christmas, FL was co-located with KSC wind tower site 2008. The site was an ungrazed grassland. The height of vegetation changed from 71 cm at the beginning of the experiment (early July) to 95 cm in middle August. Usually the soil water content at this site was also high (35% at the top layer) but overall, it was drier than UGA north site.

Both UGA systems were set up at one of the MSFC (MSFC North) site for the inter-system comparison. The site was located at the Titusville airport (28.5258°N, 80.7731°W). It was flat with several hundred meters of grass vegetation fetch. It rained the day before the comparison was carried out and the day of comparison was a cloudy day.

INSTRUMENTATION:

Both UGA sites employed the Bowen ratio Energy Balance technique. The Arizona Evapotranspiration (AZET) Bowen ratio system were used at both sites. Details of the instrument configuration were given elsewhere (Nie at al, 1992a). Briefly, net radiation was measured with a REBS net radiometer (model Q*5.5, Radiation Energy Balance Systems, Seattle, WA); soil heat flux was estimated with three heat flux plates installed at the depth of 2 cm. Thermocouples (type T, copper-constant) were placed at depth of 1 cm. A Bowen ratio apparatus was employed which consisted of two psychrometers installed in an exchanging mast at two vertical levels. Each psychrometer has two NiFe resistant thermal devices (RTDs) to measure dry-bulb and wet-bulb temperatures. The heights for the lower psychrometer and the upper psychrometer were 30 and 120 cm above canopy, respectively. All instrument were controlled by a data acquisition unit (model CR7, Campbell Scientific, Logan, UT).

Canopy reflectance and light interception were measured at each sites 3-4 times during the experimental period. A hand-held four channel band-pass radiometer (MSS, Exotech Incorporated) with a field view of 15° was used to measure ground-based spectral reflectance of the canopy. The four bands are 500-600 nm, 600-700 nm, 700-800 nm, and 800-1100 nm. Measurements were made with the radiometer looking straight down at about one meter above canopy. Readings from all four bands were taken simultaneously by a portable data logger (Omni-data Polycorder). Canopy light interception were measured with 3 sensors: an upward mounted silicon quantum sensor (model LI-190SB, LI-COR, Lincoln, NE) to measure the incoming PAR (photosynthetically active radiation); a downward mounted quantum sensor to measure reflected PAR; and a light bar (50 cm long, containing 100 GaAsP Photodiodes) to measure PAR transmitted through the canopy reached the ground by sliding the bar into the base of the canopy. Detailed information on these instruments were given elsewhere (Demetriades-Shah et. al, 1992). These measurements were made on July 9, 25 and August 6, 14, 16 at the north site; and on July 8, 24 and August 4, 14 at the south site. These dates were selected to correspond to a satellite pass-by so that ground-based measurements could compare with satellite measurement.

At the end of the experiment, an inter-sensor comparison were conducted at a site operated by Marshall Space Flight Center (MSFC). The UGA systems were compared with two other types of systems used in the field campaign: a MSFC Bowen ratio system and a MSFC eddy correlation system. Both MSFC systems employed the REBS Q*6 net radiometers and REBS soil heat flux plates (model HFT1) to measure net radiation and soil heat flux, respectively. The Bowen ratio systems used fine wire thermocouple to measure air temperature and a cooled mirror hygrometer (Model Dew-10, General Eastern Instrument Corporation) to measure dew-point temperature. The eddy correlation system consists of a one dimensional sonic anemometer (Model CA-27, Campbell Scientific, Inc., Logan, UT) with fine wire thermocouple, and a Krypton hygrometer (Model KH20, Campbell Scientific, Logan, UT).

DATA COLLECTING AND PROCESSING:

Surface energy flux data were collected and recorded on 10 minute intervals. Every 5 minutes the exchange mast switched the vertical position of the psychrometers. Differences of temperature and vapor pressure between the two heights were computed every 10 minutes to eliminate sensor bias. The Bowen ratio, defined as the ratio of sensible heat flux to latent heat flux, was calculated by:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \tag{1}$$

where β is the Bowen ratio, ΔT and Δe are the temperature and the vapor pressure differences as determined by the two psychrometers, respectively, and γ is the psychometric constant.

Latent heat flux, LE, was then computed from:

$$LE = -\frac{Q+G}{1+\beta} \tag{2}$$

where Q is the measured net radiation and G is the soil heat flux. The sensible heat flux was determined by:

$$H = -(Q + G + LE) \tag{3}$$

The Bowen ratio method fails to realistically estimate the sensible and latent heat flux under certain conditions. From Equation (2), one can see that when β approaches -1, which often happens at night, the latent heat flux approaches infinity. Therefore, when the Bowen ratio (β) falls between -0.7 to -1.3, the sensible and latent heat fluxes were estimated using an alternative method (Nie et. al, 1992b).

The evaporative fraction, which is the ratio of latent heat flux to available energy (net radiation and soil heat flux), has been a parameter used to characterize the surface energy partitioning (Shuttleworth et. al, 1989, Hall et. al, 1990), was calculated and compared for our data set.

Light reaching a canopy is distributed into one of the following: reflected, absorbed by plant canopy (intercepted), and transmitted through the canopy. The ratio of each portion to the total incident light is described by:

$$\alpha + \rho + t = 1 \tag{4}$$

where α is the absorptance, ρ is the reflectance, and t is the transmittance. The incoming, reflected and transmitted PAR were measured, and thus the fraction of photosynthetically active radiation (PAR) intercepted by the canopy, F_{IPAR}, can be estimated by:

$$F_{IPAR} = \alpha = 1 - \frac{PAR_{reflect}}{PAR_{incoming}} - \frac{PAR_{transmit}}{PAR_{incoming}}$$

RESULTS AND DISCUSSION:

Both UGA systems were set up and operating at their designated sites by July 5, 1991. This allowed testing the systems before the experimental period to assure that all the sensors perform well under the humid conditions. All the data have been submitted to MSFC.

1. Surface energy fluxes

The day-time (positive net radiation) average fluxes of both sites during the experiment (from July 8 to August 18) are given in Table 1. Figs. 1 and 2 show the daily average (24 hrs.) for the same time period. In general, net radiation (Q) was high under clear sky conditions with a value near 800 W/m² for short periods of time. However, since July and August were cloudy months in central Florida, the average values of Q for day-time or daily average varied significantly from day to day (see Table 1 and Fig. 1.1). The values for soil heat flux for the north site was larger than those of the south site (2008). Values of G (10-minute averages) can exceed -150 W/m². Because there were showers almost everyday, evaporation and transpiration rates were generally large. More than 80% of the available energy (net radiation plus soil heat flux) was dissipated into latent heat flux (LE).

Comparing the two sites, there were significant day to day variations of the fluxes due to the difference in time and duration of clouds cover. Figs. 1.1 and 1.2 show a comparison between sites of the fluxes. There were no consistent differences in net radiation between the two sites, but the day to day variability was affected by the cloudiness. Latent heat flux were also very similar at the two locations, although the vegetation cover was higher at the south site (2008). A possible explanation is that the surface of both sites were wet although the north site was more often submerged in water. The northern site (1612) appeared to have larger soil heat flux, while the southern site had greater sensible heat flux. At the northern site (1612), the Bowen ratio was consistently lower and the evaporative fraction was higher than the southern site (2008), as shown in Figure 1.3, which seems inconsistent because the northern site had less vegetation. However, the lower Bowen ratio of site 1612 is due to lower sensible heat flux (more surface water available) the higher evaporative fraction is due to the lower available energy supply (more negative soil heat flux).

Since the day to day changes in duration of cloud cover made the site comparison difficult, a different approach were used to compare the two sites. The values of fluxes were average for the whole experiment time for each period to provide an average diurnal pattern of fluxes. Fig. 1.4 shows that the net radiation values for the southern site (2008) were slightly lower, especially at midday and early afternoon. The soil heat flux was clearly greater at the northern site which is consistent with a lower vegetal cover. The north site had an average G value about -100 w/m^2 at noon, while the south site only peaked about -60. With regards to H and LE (Fig. 1.5), differences in average latent heat fluxes were negligible, but sensible heat flux was larger at the southern site (2008). The Bowen ratio was greater for the daytime period at the southern site and the evaporative fraction was higher at the northern site.

2. Intercepted PAR and ground-based spectral reflectance

Table 2 shows the ground-based spectral reflectance data and Table 3 gives the results of the canopy light interception. The means reported represent 50-60 measurements and, therefore, the mean should represent the site and the standard deviation describes the variability within the site. The normalized difference (ND) vegetation index was also calculated (Table 2) as

$$ND=\frac{Band4-Band2}{band4+Band2} \tag{6}$$

Spectral reflectance varied from 5% to 6.6% in wavebands 1 and 2, respectively; it increased to 25-30% in band 3 and 34-40% in band 4 (Table 2, Figs. 2.1 and 2.2). The variation of spectral reflectance over a site at a given day was relatively small, with the standard deviations being less than 1% in all cases. The values in Band 3 and Band 4 appeared to drop slightly with time for both site, as shows in Fig. 2.3. The differences between the two sites does not seem clear. The normalized difference (ND) varied from 0.703 to 0.767 at the north site and from 0.715 to 0.773 at the south site.

The portion of photosynthetically active radiation reflected by the canopy is relatively small. It increased slightly from 4.3% early July to 6.2 percent mid-August at the south site, and varied from 5.1% to 6.7% at the north site (Table 3). At the south site, PAR transmitted through the canopy decreased from 23.8% at the beginning of the experiment to 6.3 percent by the end of the study. At the north site, the value of transmittance varied from 37.7% to 21.4%. The intercepted PAR (F_{IPAR}) increased from 71.9% to 87.5% during the 40 days study at the south site. The values of F_{IPAR} had a range of 56.9% to 73.4% at the north site. There were greater variations in the transmitted PAR and intercepted PAR within site; as indicated by the standard deviation (Table 3). Comparing the two sites, the measured light interception was higher at the southern site than at the northern site (Fig.

2.4). This is consistent with the greater amount of vegetal cover at the southern site.

3. Inter-system comparison

Several instrument configuration were used to measure surface flux at the seven sites during CaPE. Earlier study shows that different types of instruments could make 10-20% difference in flux measurements (Nie et. al, 1992b; Fritschen et. al, 1992). It is very important to compare the systems used in any study when different types of instruments were involved; thus estimates of uncertainties related to instrumentation can be addressed.

An inter-system comparison was carried out on August 20, 1992. Four systems from UGA and MSFC were set up side by side at one site: two UGA Bowen ratio systems, one MSFC Bowen ratio system and one MSFC eddy correlation system. The FSU (Florida State University) systems did not compare with the other during this study. However, the instrument configuration used at the FSU sites were identical to that FSU used during FIFE; and the configuration used at the UGA sites were identical to those KSU (Kansas State University) used in FIFE. Those configurations were compared in several earlier comparison studies (Nie et. al, 1992, Fritschen et. al, 1992).

Diurnal variations of the parameter compared were given in Figs. 3.1-3.7. UGA1 was the system from the UGA northern site, UGA2 was the system from the UGA southern site. MSFC1 represent the eddy correlation system, and MSFC2 was the MSFC Bowen ratio system. The data analyzed was from 1630 hr of August 19, 1991 to 1630 hr of August 20, 1991.

All four systems employed bet radiometers manufacturer by REBS but two different models (Fritschen and Fritschen, 1989). Our comparison showed practically identical net radiation measurements (Fig. 3.1). The largest difference was 20 W/m^2. Soil heat flux measured by three systems (UGA1, UGA2, and MSFC2) agreed with one another surprisingly well (Figure 3.2). The maximum difference for a 30-minute average values was less than 10 W/m^2 (except for 1500hr and 1630hr) for the two different types of heat flux plates.

The exchange mechanism were out of order most of the time during the comparison, therefore, the measurements for Bowen ratio (β), sensible heat flux (H) and latent heat flux (LE) are not valid. The comparisons of sensible flux were generally good (Fig. 3.3). However, the eddy correlation system gave larger negative sensible heat flux (30-50% or 10-20 W/m^2) from 1200 hr to 1500 hr. The three Bowen ratio systems agreed quite well in measuring latent heat flux, while the eddy correlation system (MSFC1) reported significantly smaller LE (Fig. 3.4). During the day of August 20 (from 800 hr to 1600 hr) the values of MSFC1 was only about 50-60% of those reported from the other systems. The larger H and smaller LE led to a much higher Bowen ratio for system MSFC1 (Figure 3.5). The value of β for the eddy correlation system was 2-3 times as high as those of the three Bowen ratio systems.

Fig. 3.6 and 3.7 shows the comparison of air temperature and vapor pressure. MSFC2 gave lower air temperature both day and night compared to the other three systems. The difference between the two MSFC systems were about 0.5°C during the day and at night. The UGA systems agreed well with each other but reported 0.4-0.7°C higher during the day compared to MSFC1 (Fig. 3.6). The differences in vapor pressure among different instruments were unexpected. The values reported by MSFC1 was about 10 mb lower than that by MSFC2 (Fig. 3.7). The values given by the two UGA systems were identical to each other and falls in between those from the two MSFC systems. All four systems showed similar diurnal variations.

Table 4 showed the daytime average values of the parameters compared for the four system. The two types of Bowen ratio systems agreed well with difference less than 10 W/m^2 for all the fluxes. The values from the eddy correlation system were about 56% lower in latent heat flux, but the difference in sensible heat flux was small compared to the Bowen ratio system. Systematic differences in vapor pressure measurement were detected among the three systems.

SUMMARY AND CONCLUSION

Surface energy balance data were collected at two locations in central Florida from early July to middle August 1991, as part of the CaPE field campaign. Flux measurements were made continuously for 42 days (from July 8 to August 18) using the Bowen ratio energy balance technique. Ground-based spectral reflectance data and canopy light interception data were also collected several times during this period at both site, and effort were made to correspond to a satellite pass-by. The energy flux measuring systems were compared with two other types of systems used by other members of the surface flux team to address any systematic difference due to instrumentation.

Under clear conditions, net radiation can be close to 800 W/m^2 and soil heat flux exceeded 150 W/m^2 at noon time. About 80% of the available energy was dissipated to latent heat flux. Sensible heat fluxes were generally low. The two sites differed in soil heat flux and sensible heat flux, while net radiation and latent heat flux were similar, although the north site had less vegetation. Bowen ratio was about .10 to .20, with the values at the north site being consistently lower. Ground-based reflectance were also similar at the two sites varied from about 5% in the blue spectral region to 40% in the near infra-red region. PAR intercepted by canopy increased from 72% to 88% at the southern site, and the value of the northern site was about 10-15% lower.

Measurements of net radiation and soil heat flux were essentially identical for all the systems set up in the same location. The UGA Bowen ratio systems agreed well with the other Bowen ratio system in measure sensible and latent heat fluxes. The eddy correlation system given smaller values of LE and larger values of H, compared to the Bowen ratio systems. There are significant difference in vapor pressure measurements among systems.

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Table 1. Average fluxes (W/m^2) from the two UGA sites during daytime periods.

Day of Year	North Site (1612)				South Site (2008)			
	Q	LE	H	G	Q	LE	H	G
189	389.3	-287.2	-46.0	-55.9	396.7	-298.0	-62.5	-33.6
190	235.4	-194.2	-22.1	-19.0	246.8	-199.0	-37.6	-10.2
191	178.2	-141.2	-24.5	-12.4	183.1	-141.1	-32.1	-9.8
192	287.8	-205.8	-42.4	-39.5	306.7	-226.5	-59.0	-21.1
193	199.1	-148.8	-31.9	-18.3	165.7	-116.6	-45.8	-3.3
194	152.9	-112.1	-22.2	-18.6	149.8	-67.9	-56.9	-6.7
195	390.5	-287.0	-38.1	-65.3	372.4	-259.5	-80.9	-31.9
196	230.4	-130.5	6.7	13.6	259.3	-197.5	-48.3	-13.4
197	294.8	-214.8	-38.7	-41.2	270.6	-205.2	-44.7	-20.5
198	350.4	-251.1	-41.4	-57.9	283.8	-217.4	-43.7	-22.6
199	124.5	-37.9	-87.1	0.5	368.9	-288.9	-52.0	-27.9
200					305.3	-231.9	-52.9	-20.4
201					230.3	-174.1	-44.5	-11.6
202	393.1	-279.6	-34.4	-79.0	310.9	-240.0	-50.0	-20.8
203	383.6	-271.4	-51.8	-60.3	392.0	-287.6	-76.0	-28.3
204	418.5	-309.8	-41.0	-67.6	307.2	-233.8	-51.1	-22.2
205	335.4	-246.1	-38.1	-51.0	278.1	-212.7	-42.6	-22.6
206	411.8	-311.1	-44.1	-56.5	374.6	-283.4	-66.1	-25.1
207	297.4	-209.5	-41.9	-45.9	254.6	-196.8	-44.1	-13.7
208	362.9	-255.5	-56.1	-51.1	379.2	-278.6	-70.6	-29.9
209	337.9	-251.6	-41.8	-44.4	369.2	-278.6	-63.5	-26.9
210	340.6	-262.8	-42.2	-35.5	358.3	-267.8	-65.5	-24.9
211	235.3	-180.0	-35.0	-20.1	221.7	-168.3	-43.7	-9.6
212	192.8	-152.3	-30.7	-9.7	225.6	-169.2	-44.8	-11.5
213	230.3	-171.4	-34.4	-24.4	233.3	-172.9	-46.6	-13.7
214	394.5	-306.7	-37.8	-49.9	355.0	-267.9	-60.2	-26.9
215	344.8	-263.4	-39.8	-41.5	346.2	-262.6	-58.0	-25.5
216	375.2	-288.1	-42.6	-44.4	406.9	-311.4	-67.0	-28.4
217	280.5	-214.7	-43.8	-21.8	233.1	-179.2	-44.2	-9.5
218	413.0	-317.9	-44.8	-50.2	401.8	-308.3	-67.5	-25.9
219	346.1	-267.8	-39.0	-39.3	375.5	-287.8	-63.4	-24.2
220	363.2	-277.7	-43.1	-42.3	373.1	-284.8	-64.3	-23.9
221	410.3	-301.1	-56.8	-52.3	268.7	-221.5	-38.6	-8.5
222	372.5	-280.0	-46.5	-45.9	350.5	-275.0	-51.7	-23.6
223	324.6	-247.0	-36.7	-40.8	333.3	-259.9	-48.7	-24.6
224	355.8	-274.7	-37.5	-43.5	368.2	-288.6	-54.5	-25.0
225	402.1	-303.2	-51.3	-47.5	372.0	-279.0	-68.9	-24.1
226	418.8	-317.9	-51.5	-49.3	400.6	-314.9	-63.7	-21.9
227	305.7	-246.8	-32.4	-26.3	318.5	-252.9	-52.2	-13.3
228	357.5	.	.	-37.7	383.7	-274.0	-90.9	-18.8
229					366.5	-274.7	-74.9	-16.8
230					230.7	-185.0	-43.0	-2.6

Table 2. Ground-Based Spectral Reflectance at UGA Site

SITE	DOY	Band1		Band2		Band3		Band4		ND	NDE
		Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
1612	190	0.059	0.0010	0.050	0.0010	0.284	0.0045	0.378	0.0053	0.767	0.0046
1612	206	0.065	0.0009	0.059	0.0011	0.270	0.0036	0.364	0.0048	0.719	0.0046
1612	218	0.066	0.0008	0.065	0.0010	0.261	0.0038	0.377	0.0055	0.703	0.0039
1612	226	0.064	0.0007	0.058	0.0006	0.267	0.0037	0.357	0.0049	0.717	0.0037
1612	228	0.060	0.0009	0.054	0.0008	0.269	0.0039	0.359	0.0047	0.736	0.0036
2008	189	0.056	0.0010	0.050	0.0012	0.297	0.0056	0.400	0.0074	0.773	0.0068
2008	205	0.061	0.0018	0.058	0.0022	0.288	0.0060	0.384	0.0071	0.736	0.0086
2008	216	0.057	0.0007	0.056	0.0013	0.251	0.0038	0.340	0.0050	0.715	0.0084
2008	226	0.054	0.0006	0.052	0.0011	0.266	0.0035	0.372	0.0047	0.754	0.0066

Table 3. Canopy PAR Distribution at UGA Sites

Site	DOY	Reflectance Mean	Reflectance Std	Transmittance Mean	Transmittance Std	Interception Mean	Interception Std
1612	190	0.067	0.0050	0.266	0.1078	0.667	0.1088
1612	206	0.054	0.0080	0.377	0.1843	0.569	0.1861
1612	226	0.051	0.0038	0.300	0.1385	0.649	0.1379
1612	228	0.052	0.0028	0.214	0.1134	0.734	0.1132
2008	189	0.043	0.0035	0.238	0.1192	0.719	0.1199
2008	205	0.055	0.0040	0.116	0.1008	0.829	0.1015
2008	226	0.062	0.0023	0.063	0.0529	0.875	0.0536

Table 4. Comparison of day-time (Q>0) average fluxes for 4 systems used in CaPE

parameter	UGA1	UGA2	MSFC1	MSFC2
Net radiation (W/m^2)	101	105	107	103
Soil heat flux (W/m^2)	-6	-9		-8
Sensible heat flux (W/m^2)	-12	-15	-19	-10
Latent heat flux (W/m^2)	-83	-81	-45	-84
Air temperature (°C)*	25.92	25.81	25.64	25.28
Vapor Pressure (mb)*	30.06	29.94	25.72	33.48

Fig. 1.1 Daily average (24 hrs.) surface fluxes of net radiation for two CaPE sites (1612 and 2008).

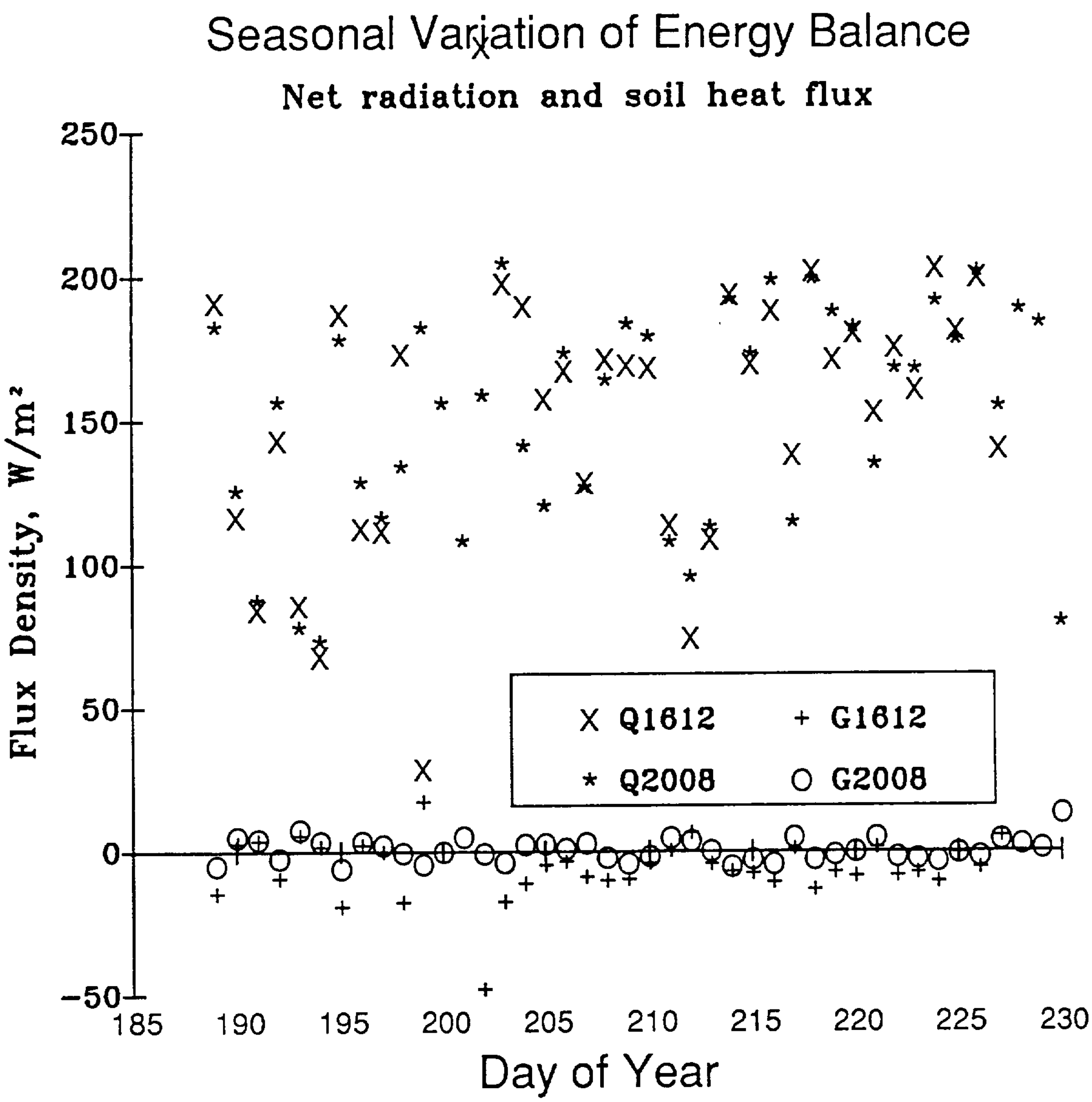


Fig. 1.2 Daily average (24 hrs.) surface fluxes (sensible and latent heat) for two CaPE sites (1612 and 2008).

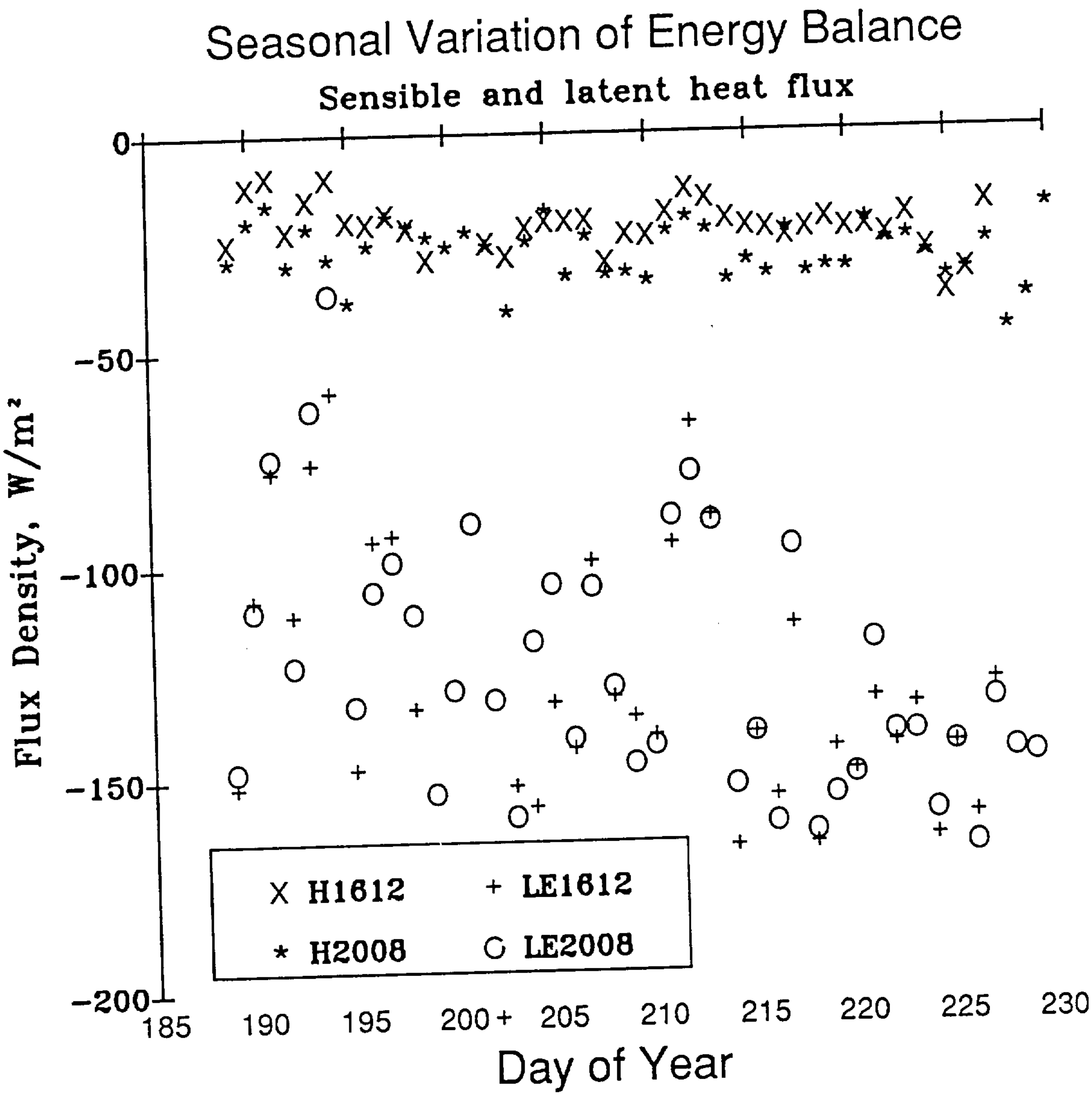


Fig. 1.3 The daily average Bowen ratio and evaporative fraction for the two CaPE sites (2008 and 1612).

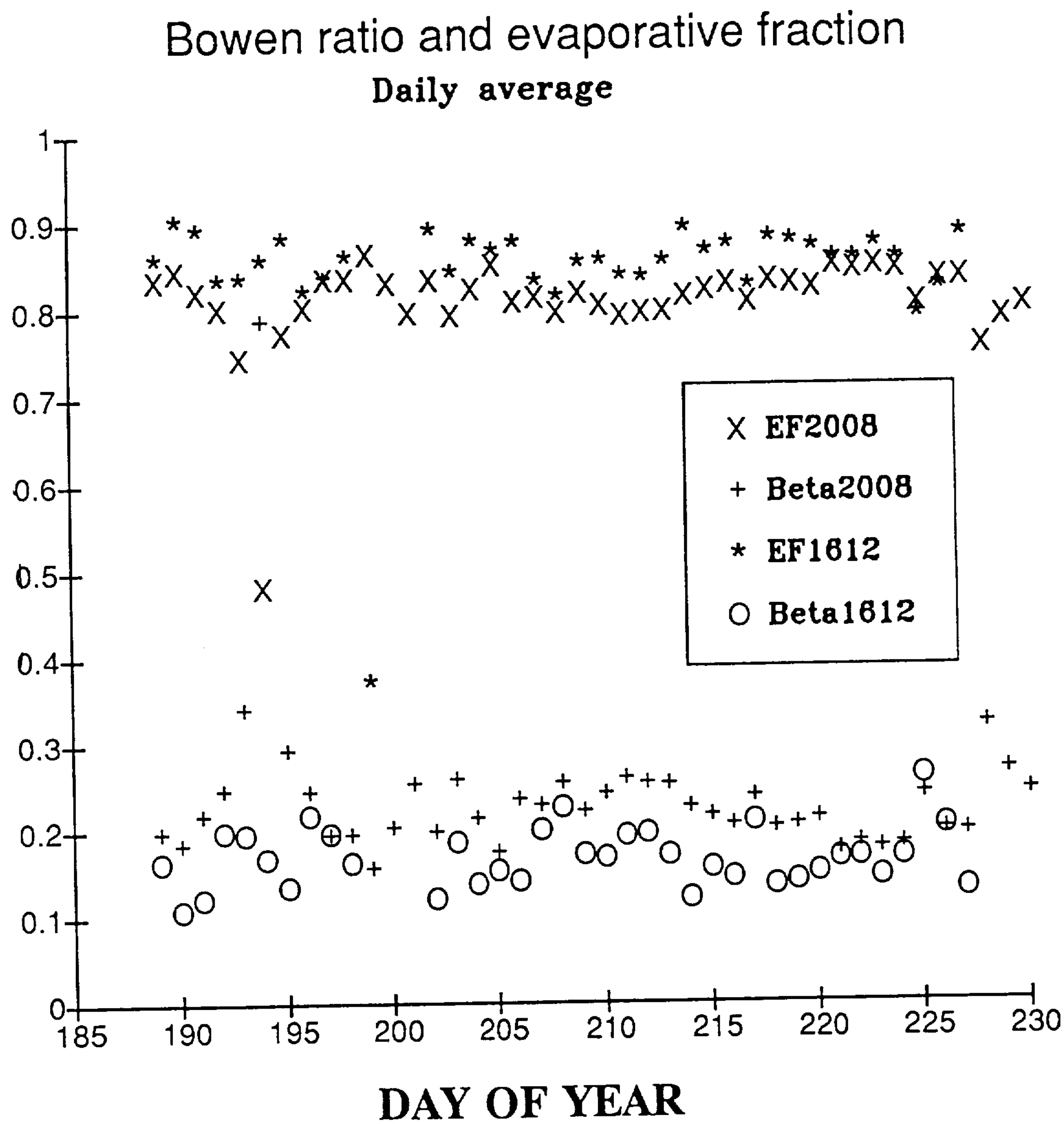


Fig. 1.4 The diurnal variation of averaged net radiation and soil heat flux for the two CaPE sites (2008 and 1612).

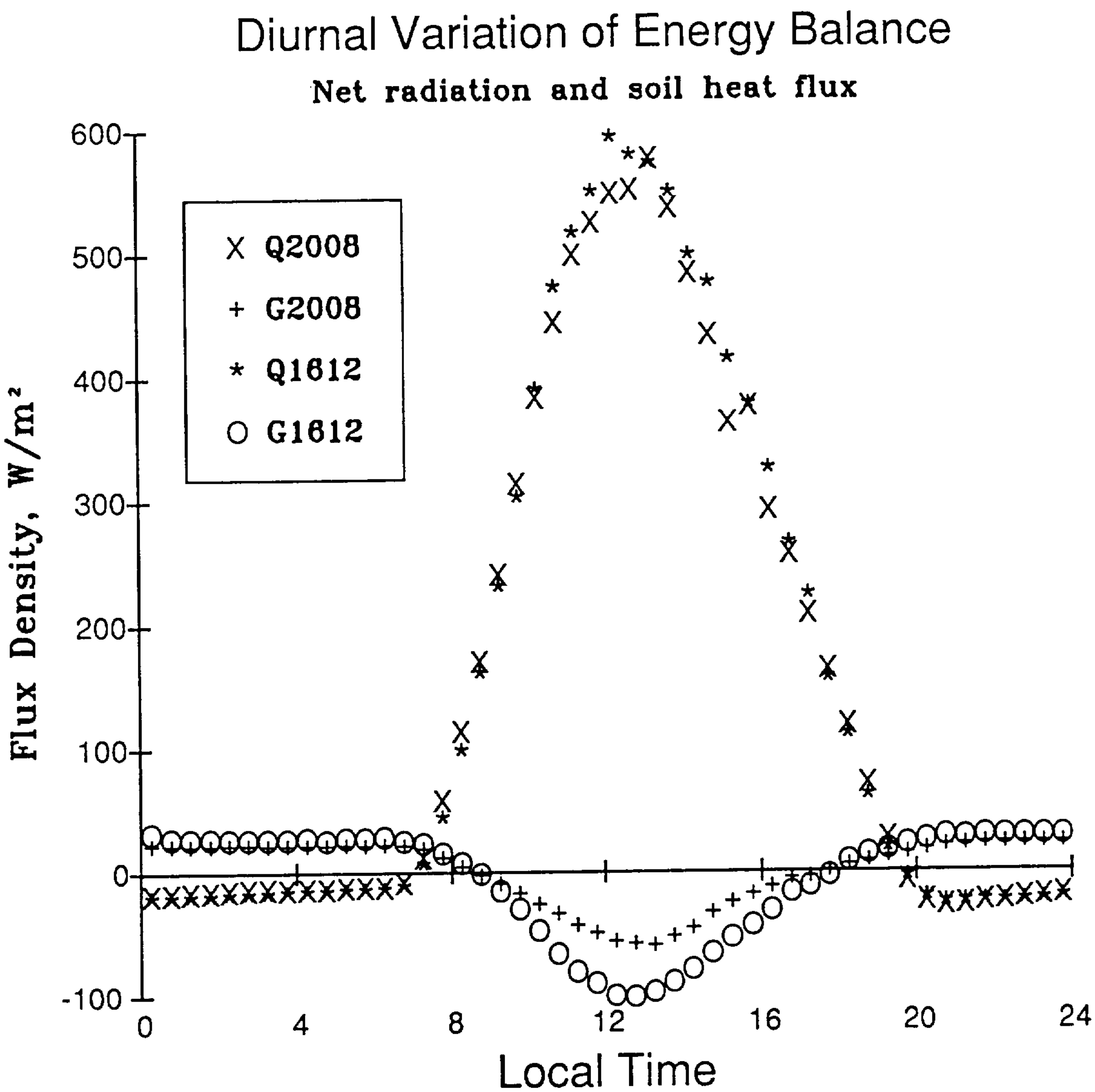


Fig. 1.5 The diurnal variation of averaged sensible and latent heat flux for the two CaPE sites (2008 and 1612).

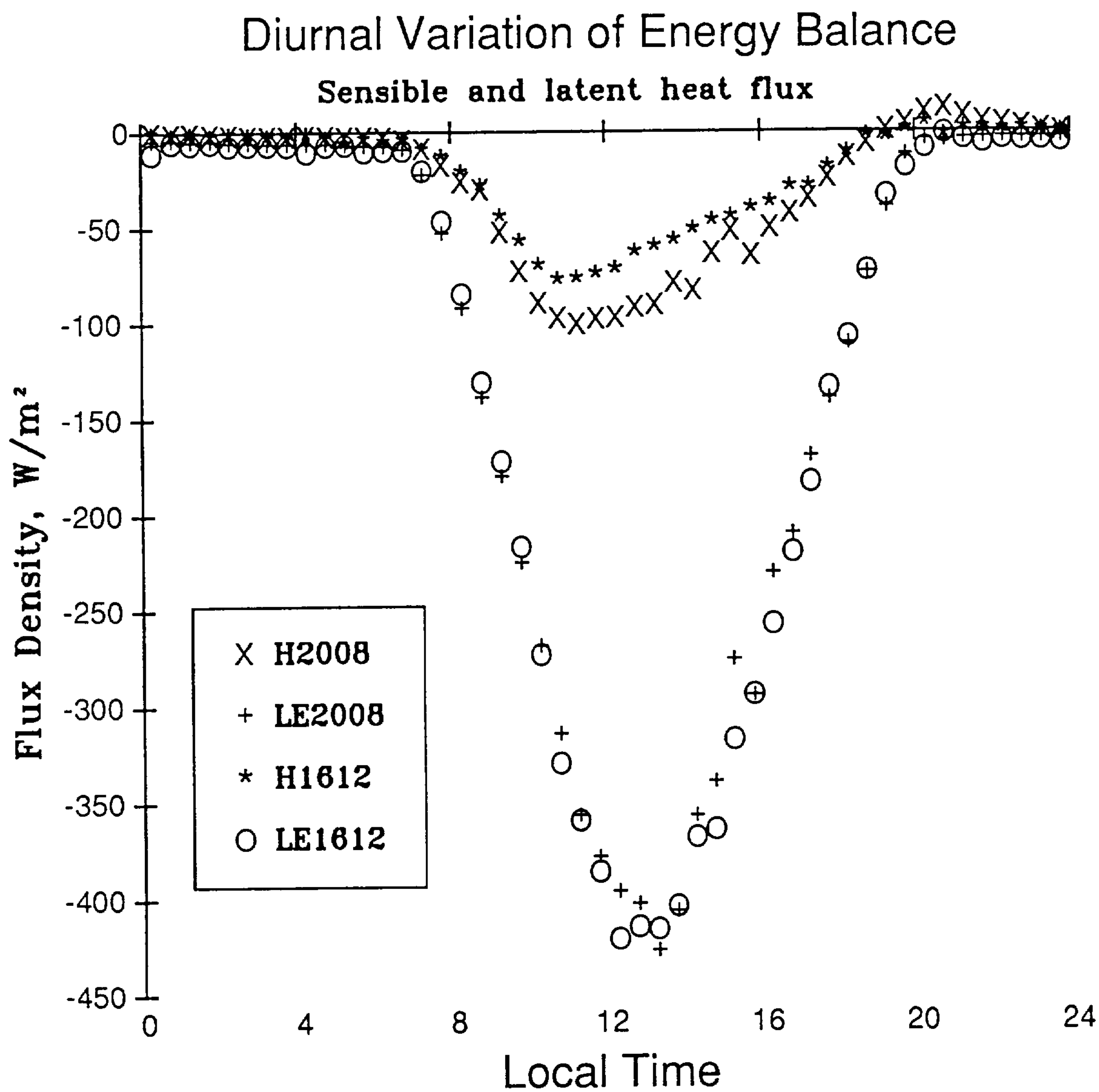


Fig. 1.6 The diurnal variation of averaged Bowen ratio and evaporative fraction for the two CaPE sites (2008 and 1612).

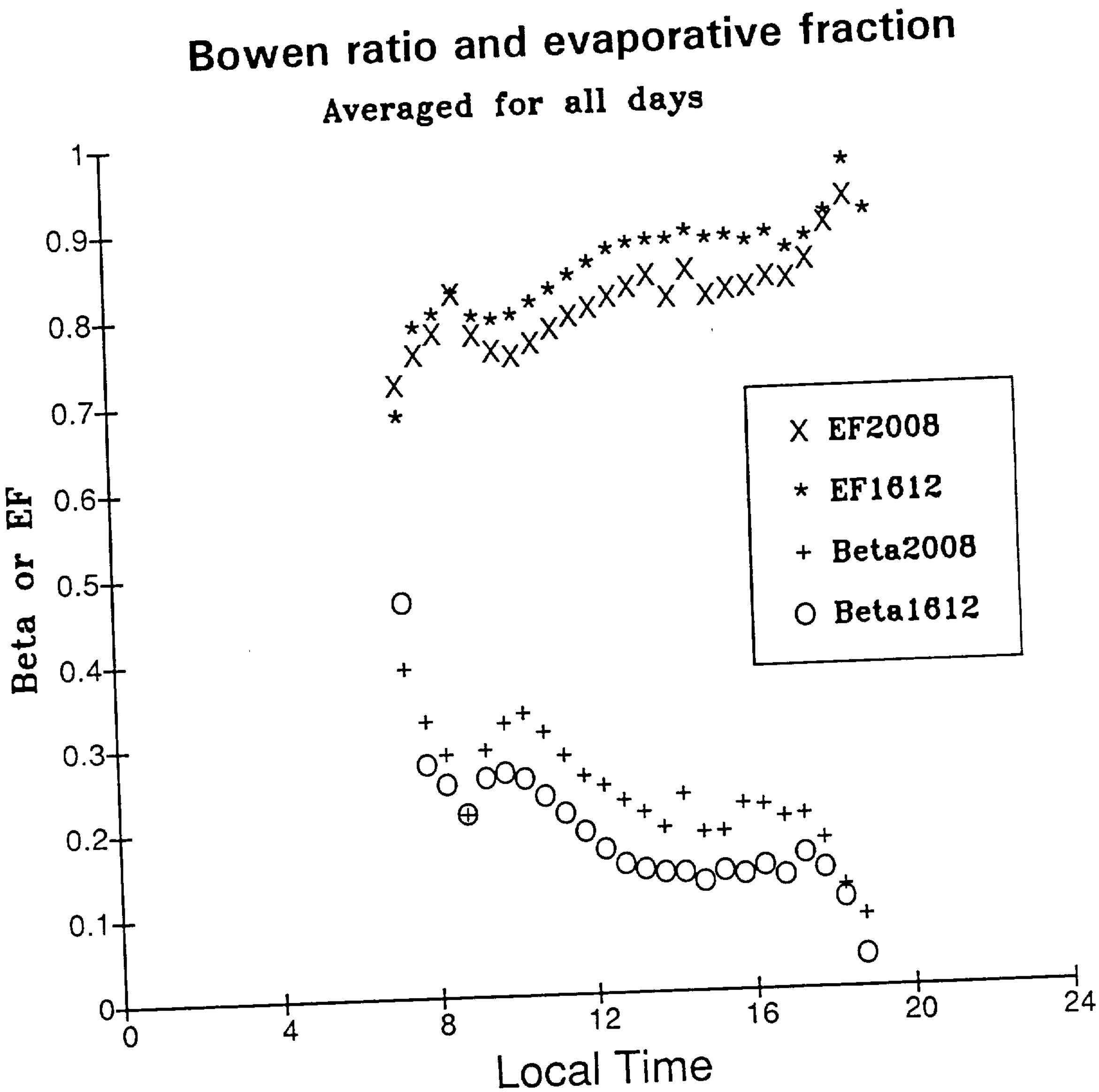


Fig. 2.1 The spectral reflectance for five days during the CaPE experiment for the north site (1612) waveband 1, 2, 3 and 4 are 500-600 nm, 600-700 nm, 700-800 nm, and 800-1100 nm, respectively.

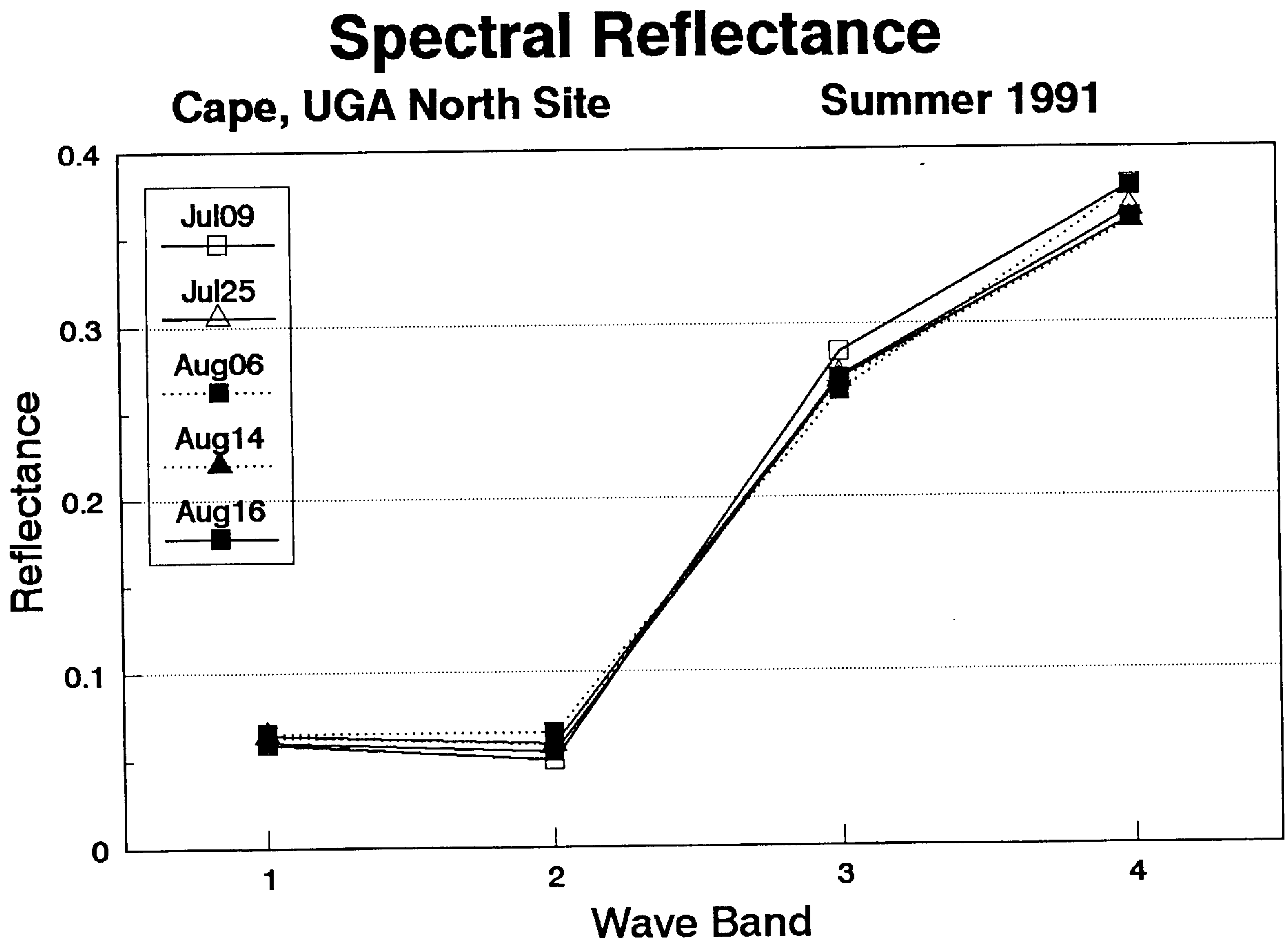


Fig. 2.2 The spectral reflectance for four days during CaPE experiment for the south site (2008).

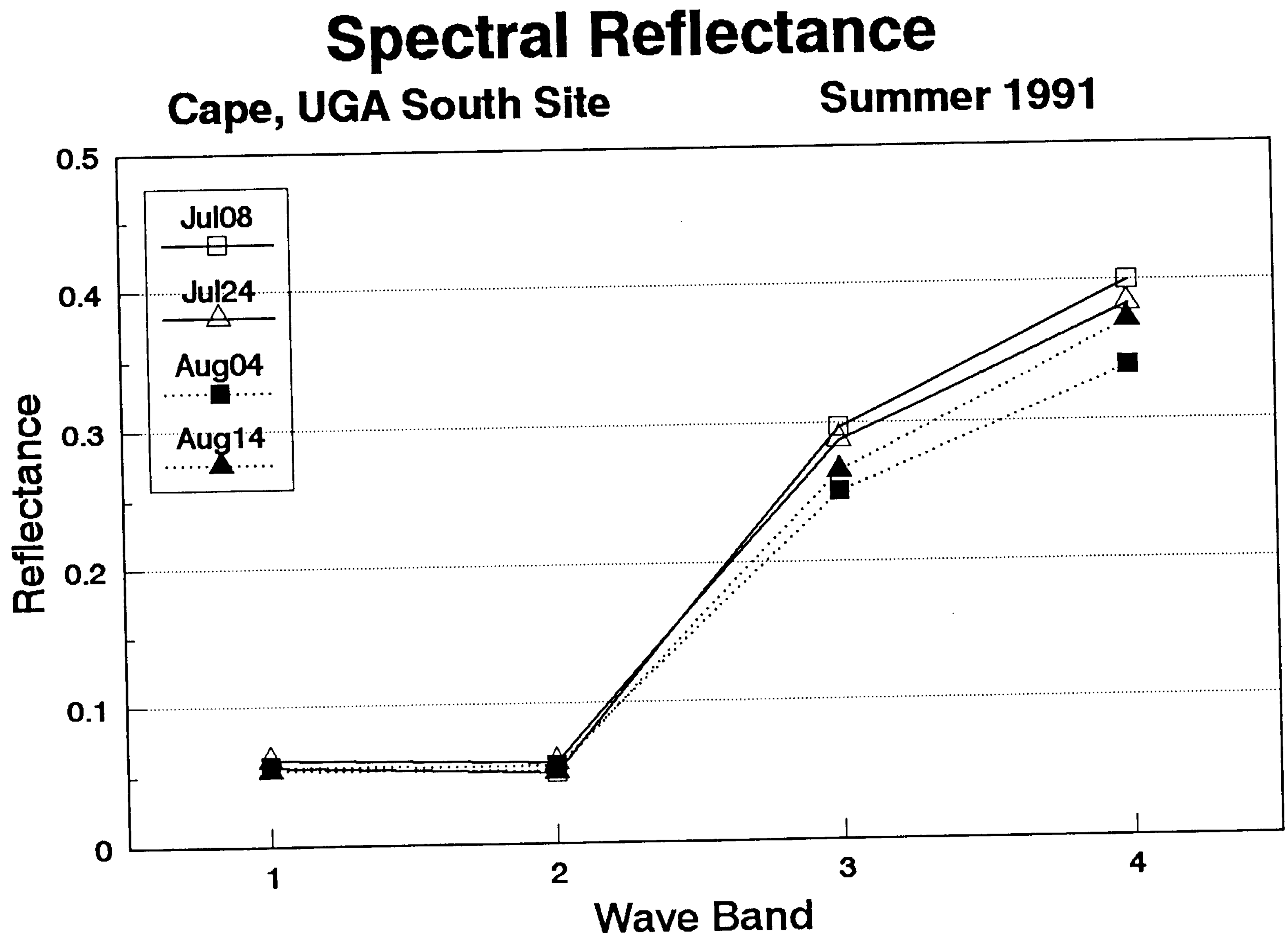


Fig. 2.3 Comparisons of the seasonal trends in the near infrared reflectance from the two CaPE sites.

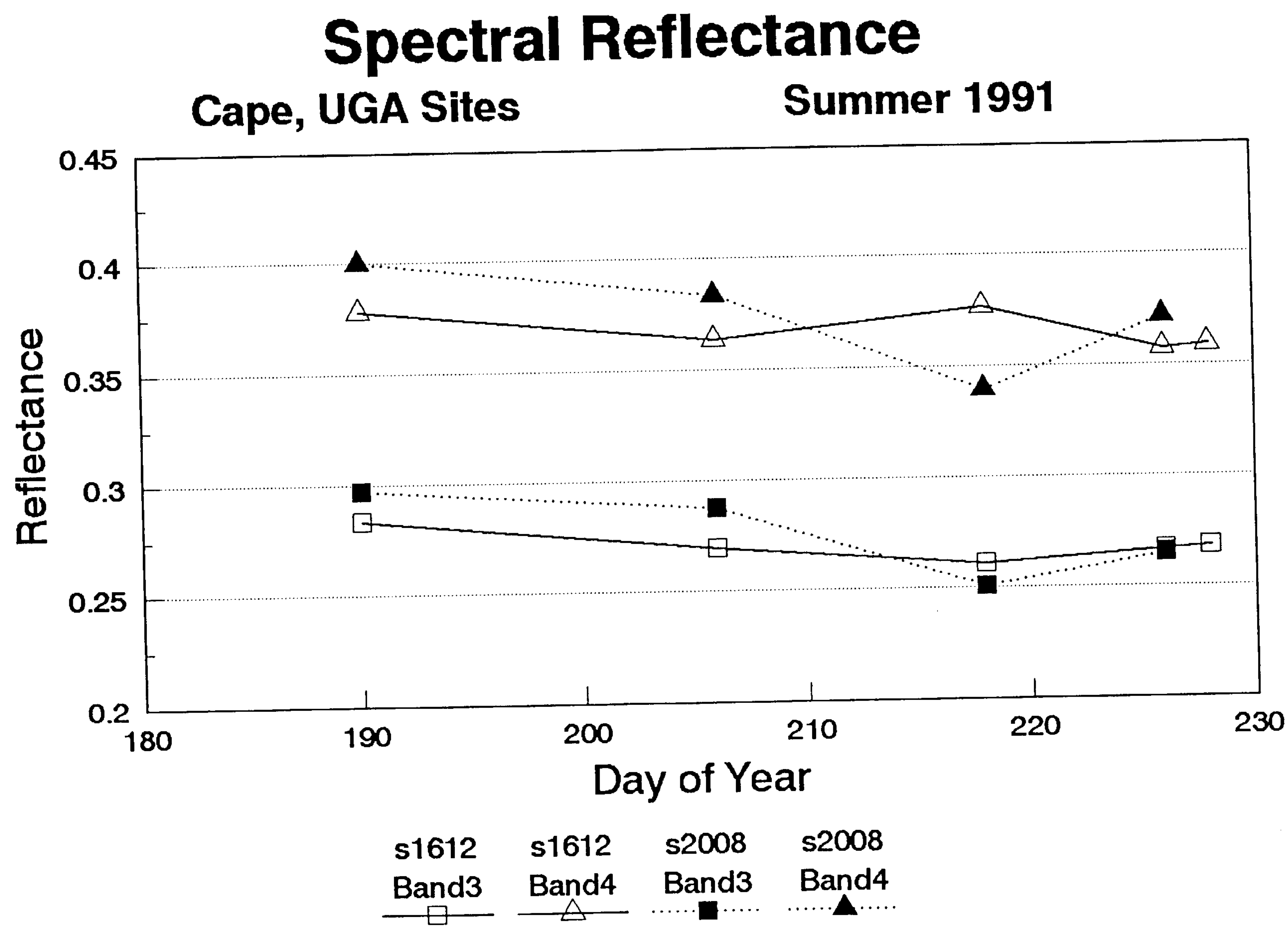


Fig. 2.4 The season trends in light (PAR) reflectance, transmittance and interception by the canopy at sites 2008 and 1612.

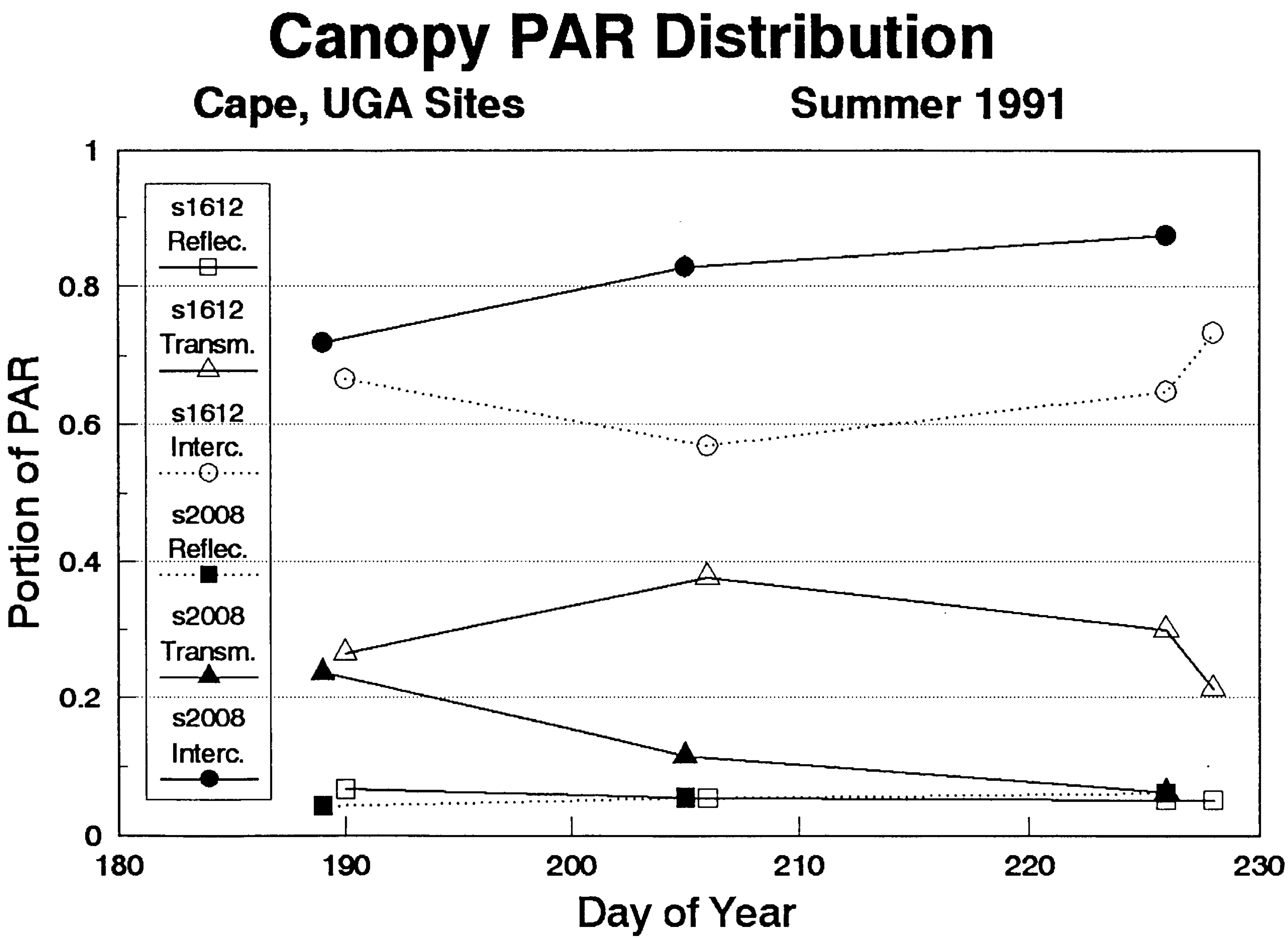


Fig. 3.1

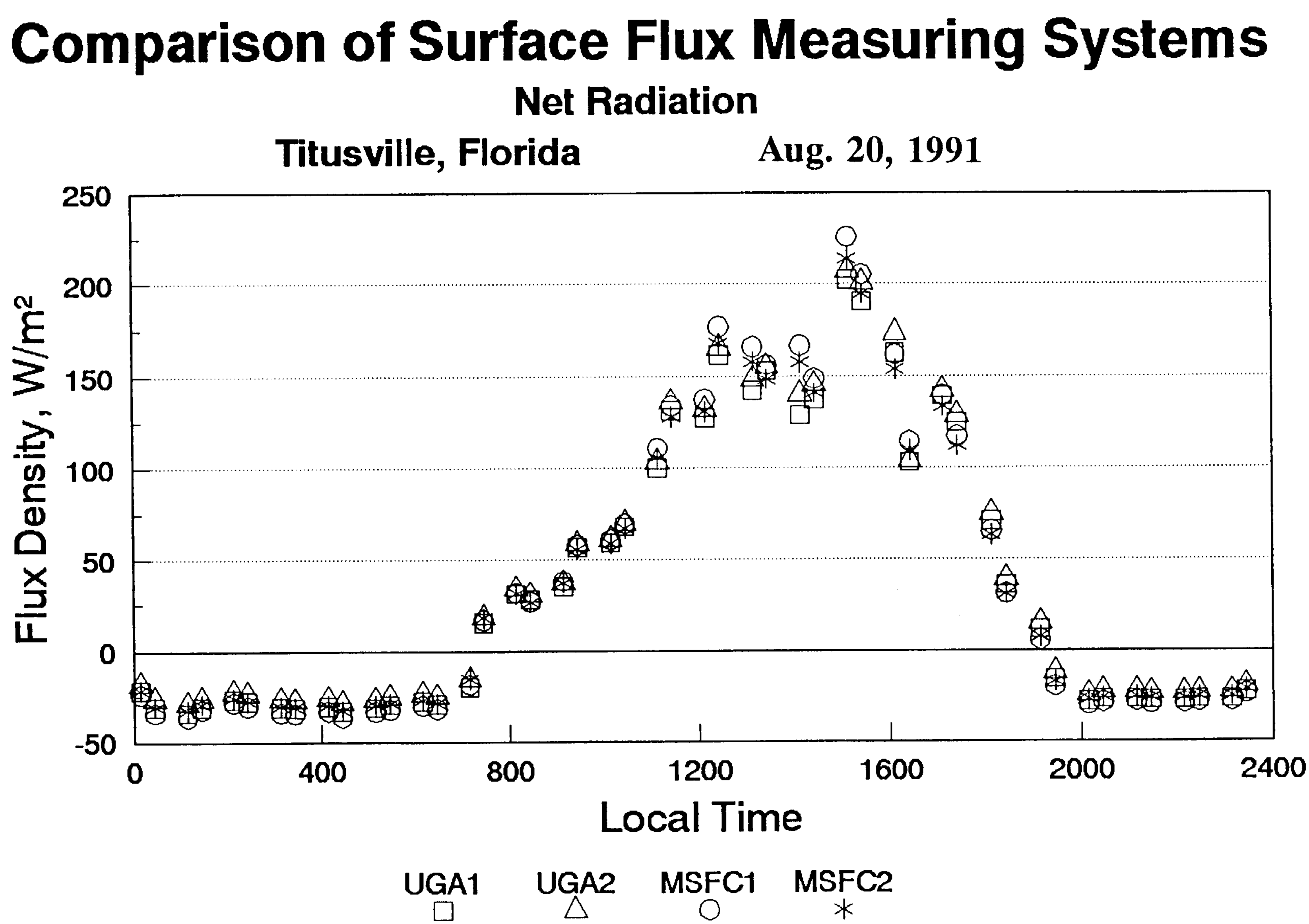
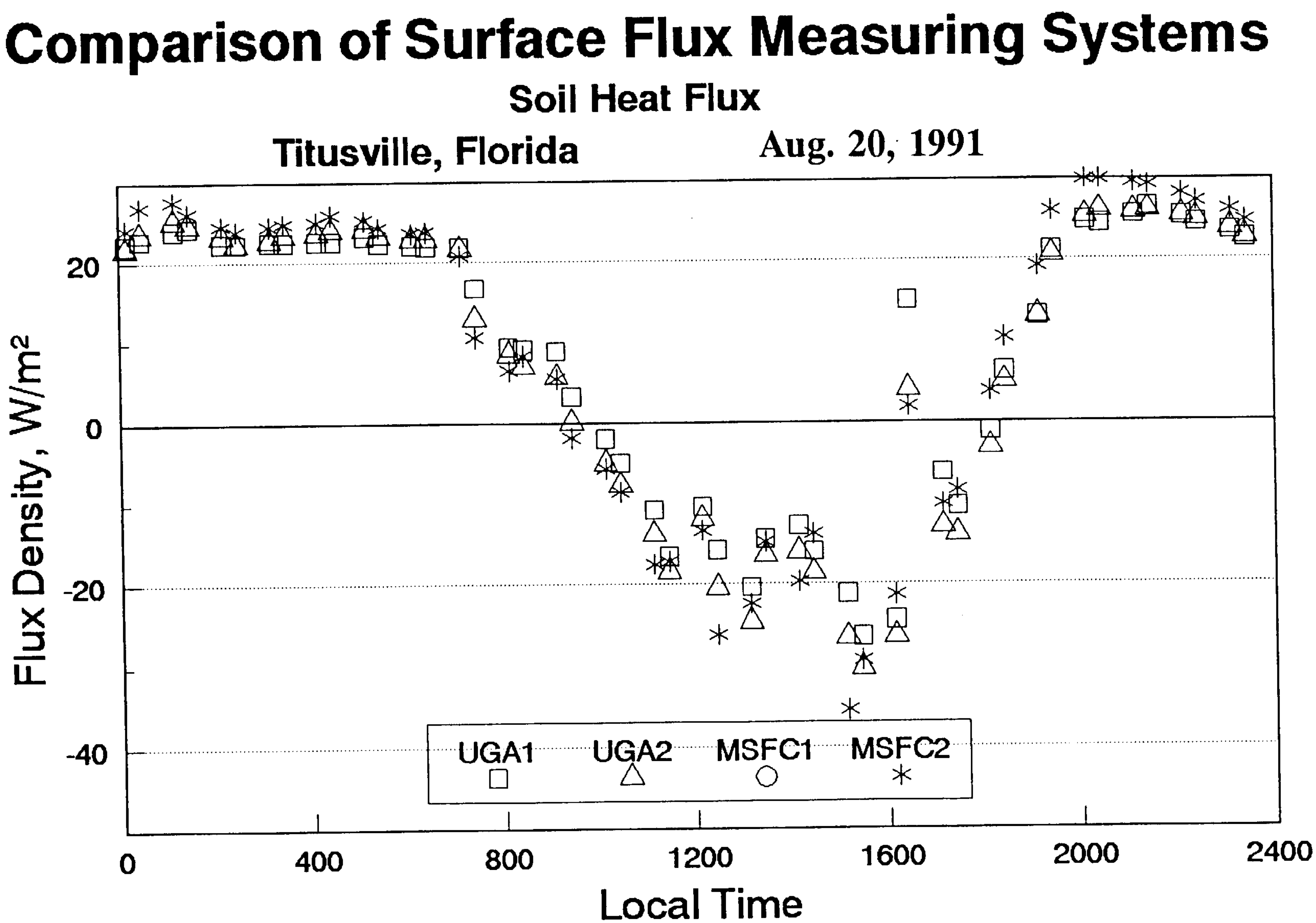

Comparison of Surface Flux Measuring Systems
Net Radiation
Titusville, Florida
Aug. 20, 1991
Flux Density, W/m²
250
200
150
100
50
0
-50
0
400
800
1200
1600
2000
2400
Local Time
UGA1
UGA2
MSFC1
MSFC2

Fig. 3.2



Comparison of Surface Flux Measuring Systems
Soil Heat Flux
Titusville, Florida
Aug. 20, 1991
Flux Density, W/m2
20
0
-20
-40
0
400
800
1200
1600
2000
2400
Local Time
UGA1
UGA2
MSFC1
MSFC2

Fig. 3.3

Comparison of Surface Flux Measuring Systems

Sensible Heat Flux

Titusville, Florida **Aug. 20, 1991**

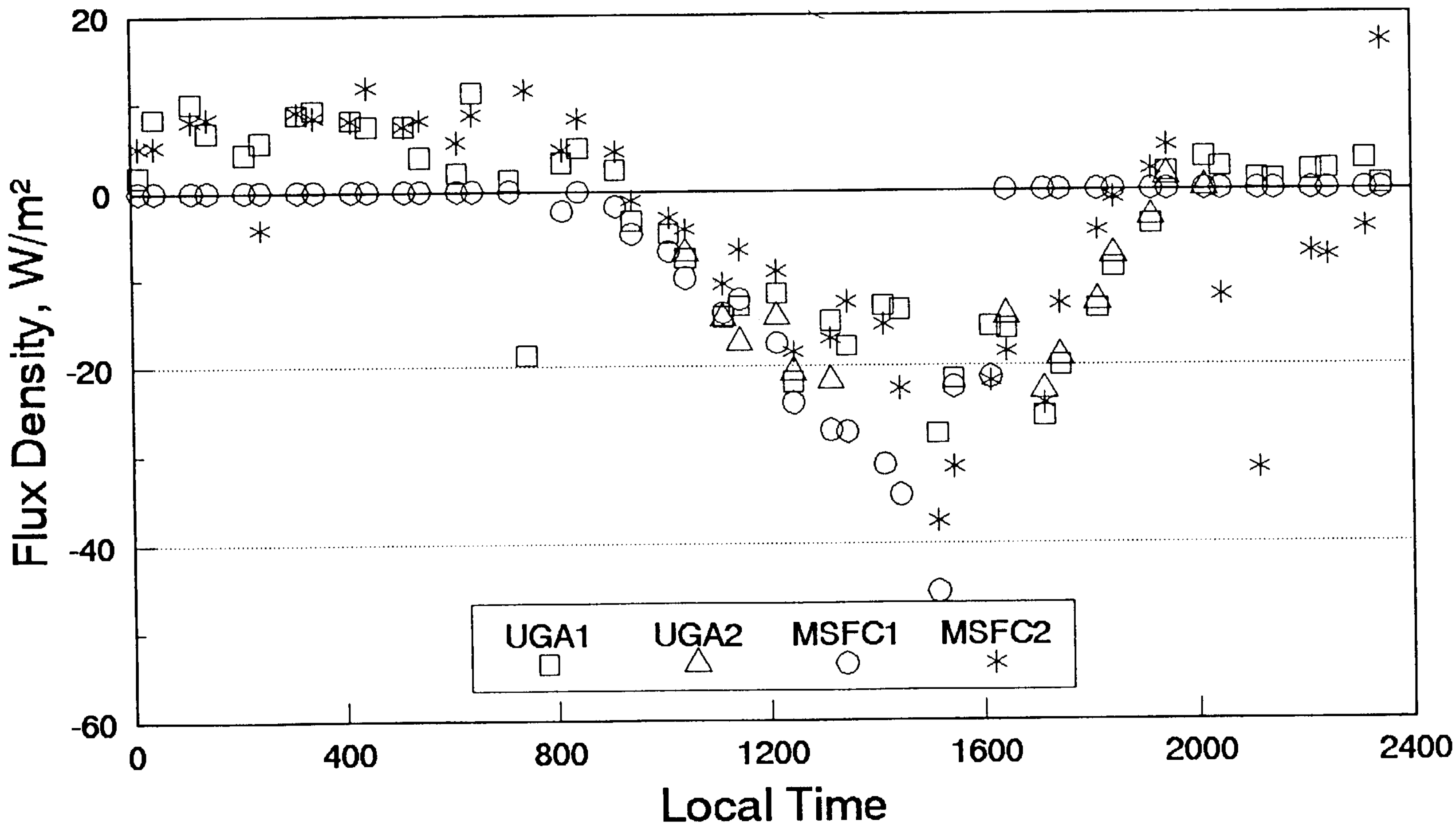


Fig. 3.4

Comparison of Surface Flux Measuring Systems

Latent Heat Flux

Titusville, Florida Aug. 20, 1991

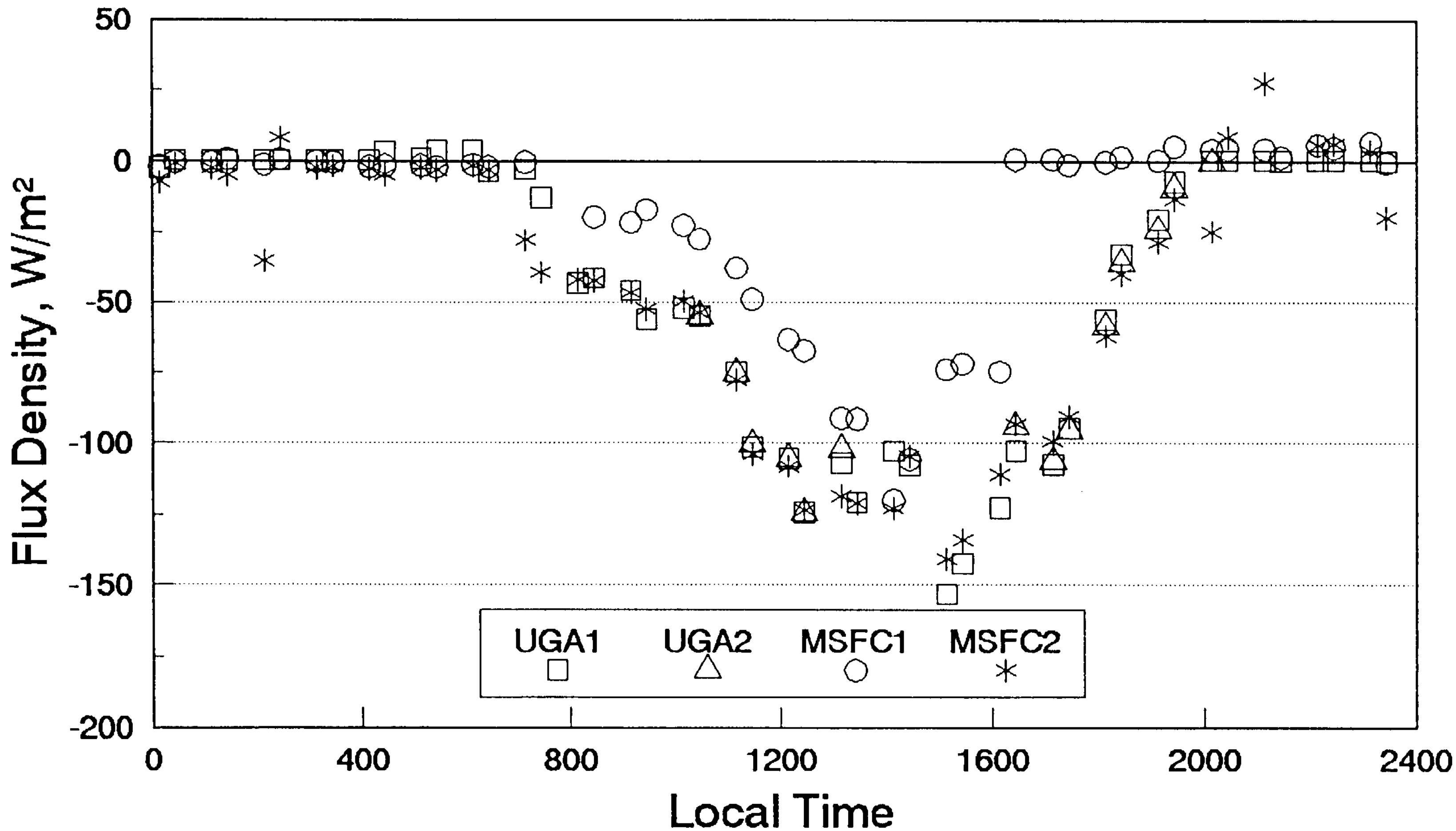


Fig 3.5

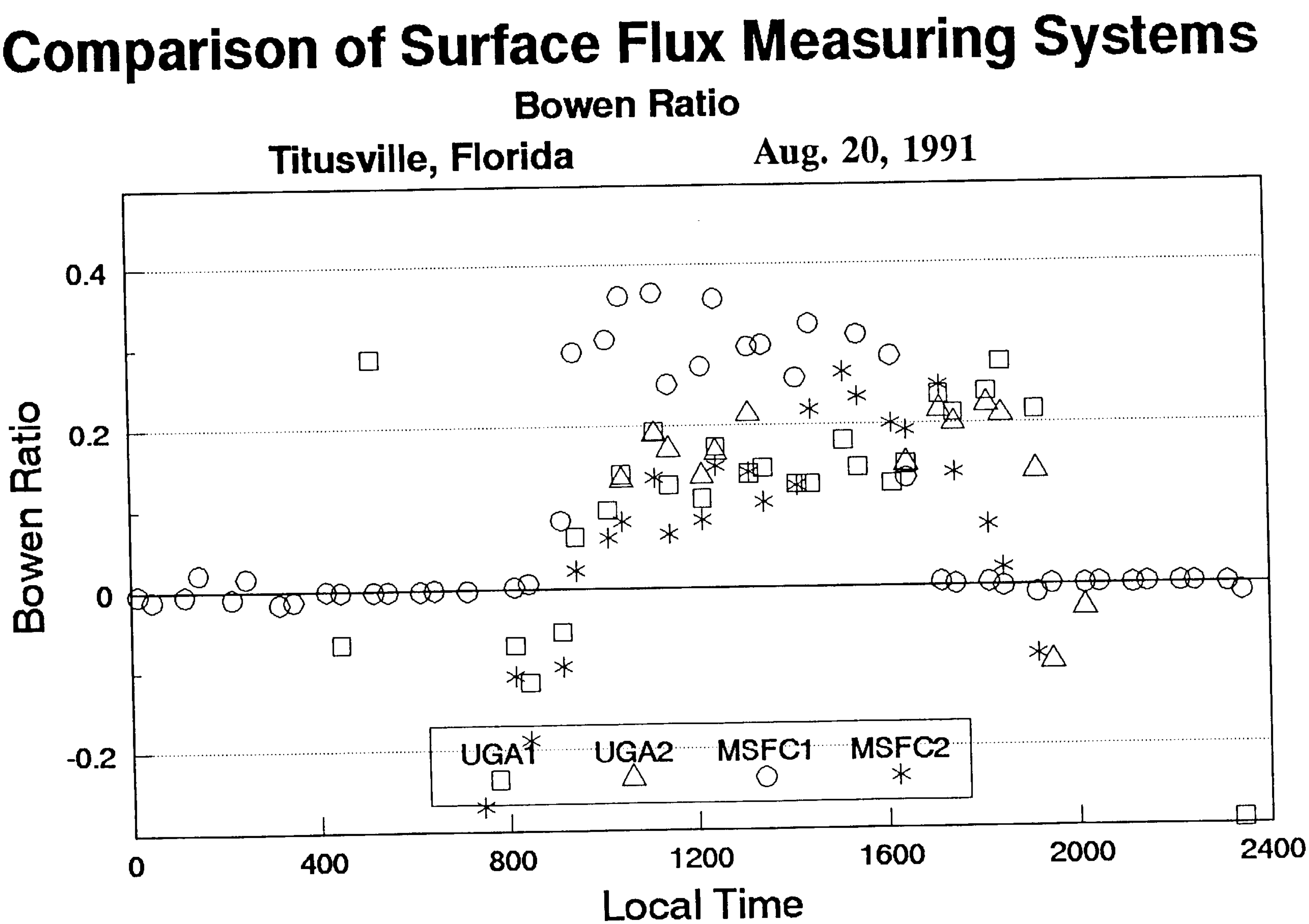

Comparison of Surface Flux Measuring Systems
Bowen Ratio
Titusville, Florida
Aug. 20, 1991
Bowen Ratio
0.4
0.2
0
-0.2
0
400
800
1200
1600
2000
2400
Local Time
UGA1
UGA2
MSFC1
MSFC2

Fig. 3.6

Comparison of Surface Flux Measuring Systems

Air Temperature

Titusville, Florida Aug. 20, 1991

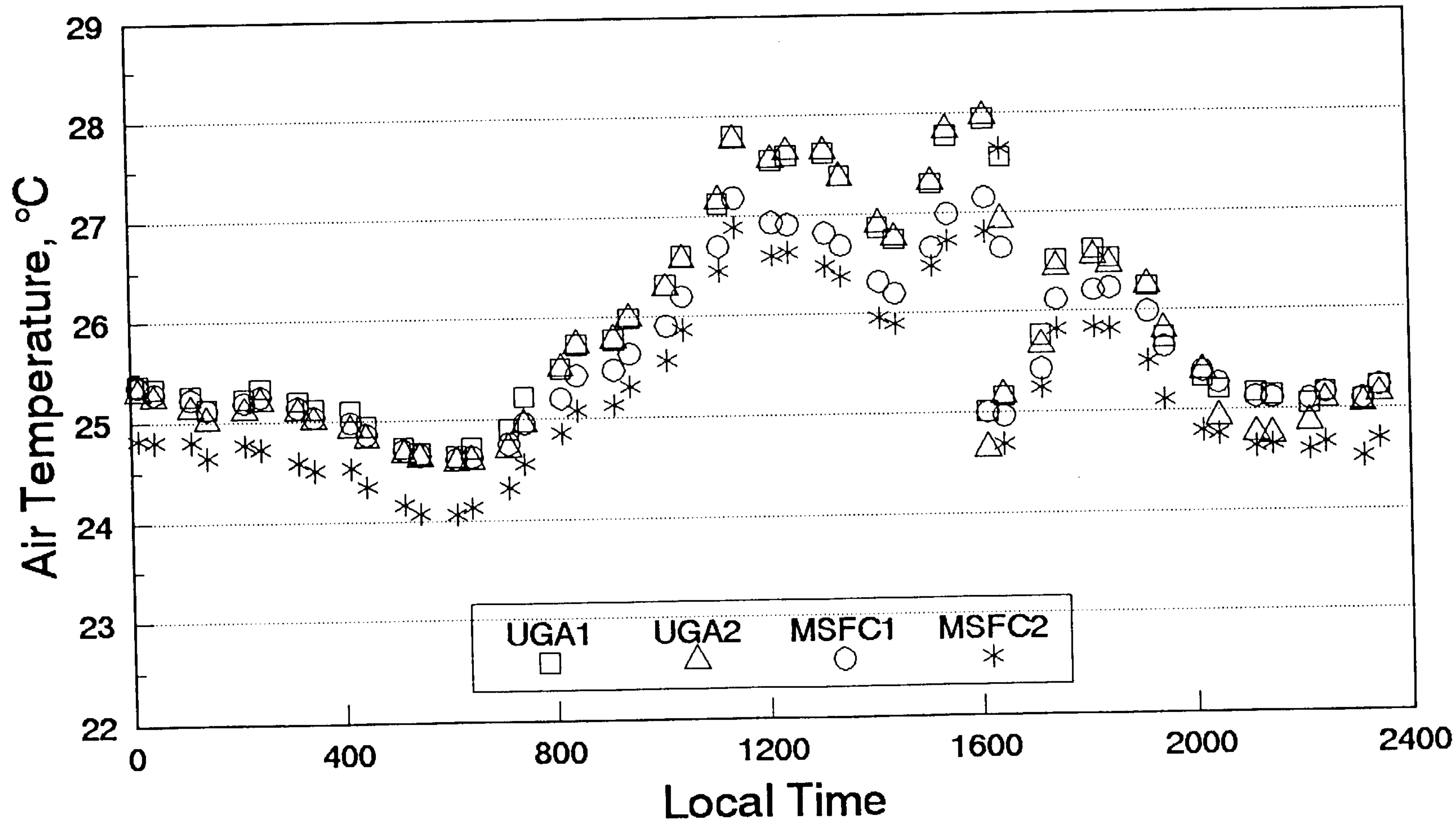


Fig. 3.7

Comparison of Surface Flux Measuring Systems

Vapor Pressure, mb

Titusville, Florida Aug. 20, 1991