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EVALUATION OF SURFACE ENERGY AND RADIATION BALANCE SYSTEMS FOR FIFE

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ABSTRACT

The energy balance and radiation balance components were determined at six sites during the First International Satellite Land Surface Climatology Project Field Experiment (FIFE) conducted south of Manhattan, KS during the summer of 1987. The objectives of the University of Washington effort were: (1) to determine the effect of slope and aspect, throughout a growing season, on the magnitude of the surface energy balance fluxes as determined by the Energy Balance Method (EBM); (2) to investigate the calculation of the soil heat flux density at the surface as calculated from the heat capacity and the thermal conductivity equations; and (3) to evaluate the performance of the Surface Energy and Radiation Balance System (SERBS).

Automatic Surface Energy and Radiation Balance Systems (SERBS) were operated continuously from May 25 till October 17 (146 days) at six sites. During intensive campaigns, the sites were serviced daily if weather permitted. Between the intensive campaigns, the sites were serviced weekly. A total of 876 station days were possible during the recording period. Data gaps amounted to 14% of the time if total or part days were counted as missing days. About 5 % of the data gaps can be filled in by completing the part days. All things considered, the systems operated better than expected for continuous data collection.

A total of 17 variables were monitored at each site. They included net, solar (up and down), total hemispherical (up and down), and diffuse radiation, soil temperature and heat flux density, air and wet bulb temperature gradients, wind speed and direction, and precipitation.

Most of the since the field season has been spent on data analysis and quality control. Consequently, little time has been available for detailed analysis. At present, all of the data has been processed. Selected variables for the four IFC's have submitted to the data bank. Additional quality checking is required before submitting the rest of the data.

A preliminary analysis of the data, for the season, indicate that variables including net radiation, air temperature, vapor pressure and wind speed were quite similar at the sites even though the sites were as much as 16 km apart and represented the four cardinal slopes and the top of a ridge. Daily average net radiation for the period was 13.52 $\pm$ 0.15 MJ $(m^2\ day)^{-1}$. The variable showing the largest site differences was soil heat flux density. The average value was -0.50 MJ $(m^2\ day)^{-1}$ with a standard deviation of $\pm$ 0.40 MJ $(m^2\ day)^{-1}$.

The latent heat flux density averaged -10.37 $\pm$ 0.49 MJ $(m^2\ day)^{-1}$ or -4.27 $\pm$ 0.20 mm day^{-1}. The accumulated amount for the period was -615 $\pm$ 29 mm. The sensible heat flux density for the period averaged 150 MJ $(m^2\ day)^{-1}$. The Bowen ratio was low during most of the season increasing sharply toward the end of the season after a long dry spell.

The average Bowen ratio was 0.27. About 80 % of the available energy was converted into latent heat flux density.

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1. INTRODUCTION

The major objective of the International Satellite Land Surface Climatology Project (ISLSCP) is to develop methodologies for deriving quantitative information concerning land surface climatological variables from satellite observations of the radiation reflected and emitted by the Earth. Such quantitative information is required to:

(1) monitor global scale changes of the land surface caused by climatic fluctuations or by human activities,

(2) further develop mathematical models designed to predict or simulate climate on various time scales, and

(3) permit inclusion of land surface climatological variables in diagnostic and empirical studies of climatic variations.

The research program to study the above objectives (First International Satellite Land Surface Climatology Project Field Experiment, FIFE) was conducted over a native prairie near Manhattan, KS during the summer of 1987. The research program required measurements of variables and fluxes at the surface, in the atmosphere, and from space.

Measurements of surface energy and surface radiation fluxes and other environmental variables were required at 22 locations in the experimental area, 15 km^2 to form an areal composite of the surface conditions.

The University of Washington group (UW) made measurements of the surface conditions at six sites as part of the of the surface flux group. Specific objectives of the UW research were:

(1) to determine the effect of slope and aspect, throughout a growing season, on the magnitude of the surface energy balance fluxes as determined by the Energy Balance Method (EBM);

(2) to investigate the calculation of the soil heat flux density at the surface as calculated from the heat capacity and the thermal conductivity equations; and

(3) to evaluate the performance of the Surface Energy and Radiation Balance System (SERBS).

Other objectives will be the subject of papers.

This report contains the details of the measurement program, a summary and status of the data collected, an evaluation of the SERBS, and manuscripts prepared and papers presented to date. Detailed evaluation of the voluminous data will require additonal time

2. THE SITES

The **EBM** using **SERBS** was used to evaluate the energy and radiation balances at six sites. The location of the sites is shown in Figure 2.1. The letter before the site number indicates the aspect of the slope at the site. Sites E34 and E36 had easterly aspects, site W20 was westerly, site S40 was southerly, site N42 was northerly, while site T44 was located on the top of a ridge (See Table 2.1 for specifics of the sites). Site E34 was located on the steepest slope.

The dead grass from the previous season was burned on all sites except 36 about the middle of April, 1987. Site 36 was grazed over winter. The vegetation was a mixture of native grasses. The dominant grasses are big bluestem **Andropogon geradii** and Indiangrass **Sorghastrum nutans**.

3. SURFACE ENERGY AND RADIATION BALANCE SYSTEMS

The **SERBS** is an automatic system for the collection and processing of surface energy and radiation balance data. It is composed of a data acquisition system, sensors and automatic exchange mechanism. The **EBM** method is better suited for evaluating energy fluxes on slopes than other meteorological methods because of the smaller fetch requirement (Fritschen, et al, 1983).

3.1 Data Acquisition System

The data acquisition portion utilizes a small, inexpensive personal computer (NEC PC-8201A) to control the Automatic Exchange Mechanism (**AEM**) and to sample, process, and store the data. A 16 channel analog input data acquisition system (Remote Measurement Systems, ADC-1) was used for data acquisition. The data system had two voltage ranges, $\pm$ 20 mV and $\pm$ 400 mV (systems 2 and 3 had $\pm$ 200mV ranges). In addition, either of two offset voltages could be added to the 20 mV range and are used to increase the sensitivity of the temperature sensors. The offset voltages were supplied through the use of one constant current source and a series string of precision resistors. Two other constant current sources supplied the various temperature sensors. A 5 V regulator supplied power to the data system while a 6 V regulator supplied power to the computer. The sensors were interfaced to the terminal strips supplied on the ADC-1 by means of seven plug connectors on the auxiliary module.

The computer directed the ADC-1 to sample the data channels at 30-s intervals, with digital information being passed to the computer via an RS-232 port. The computer also activated the **AEM** every 6 minutes to interchange the psychrometers. After activation, the computer delayed sampling for three minutes to allow the psychrometers to attain equilibrium at their new locations. Under computer

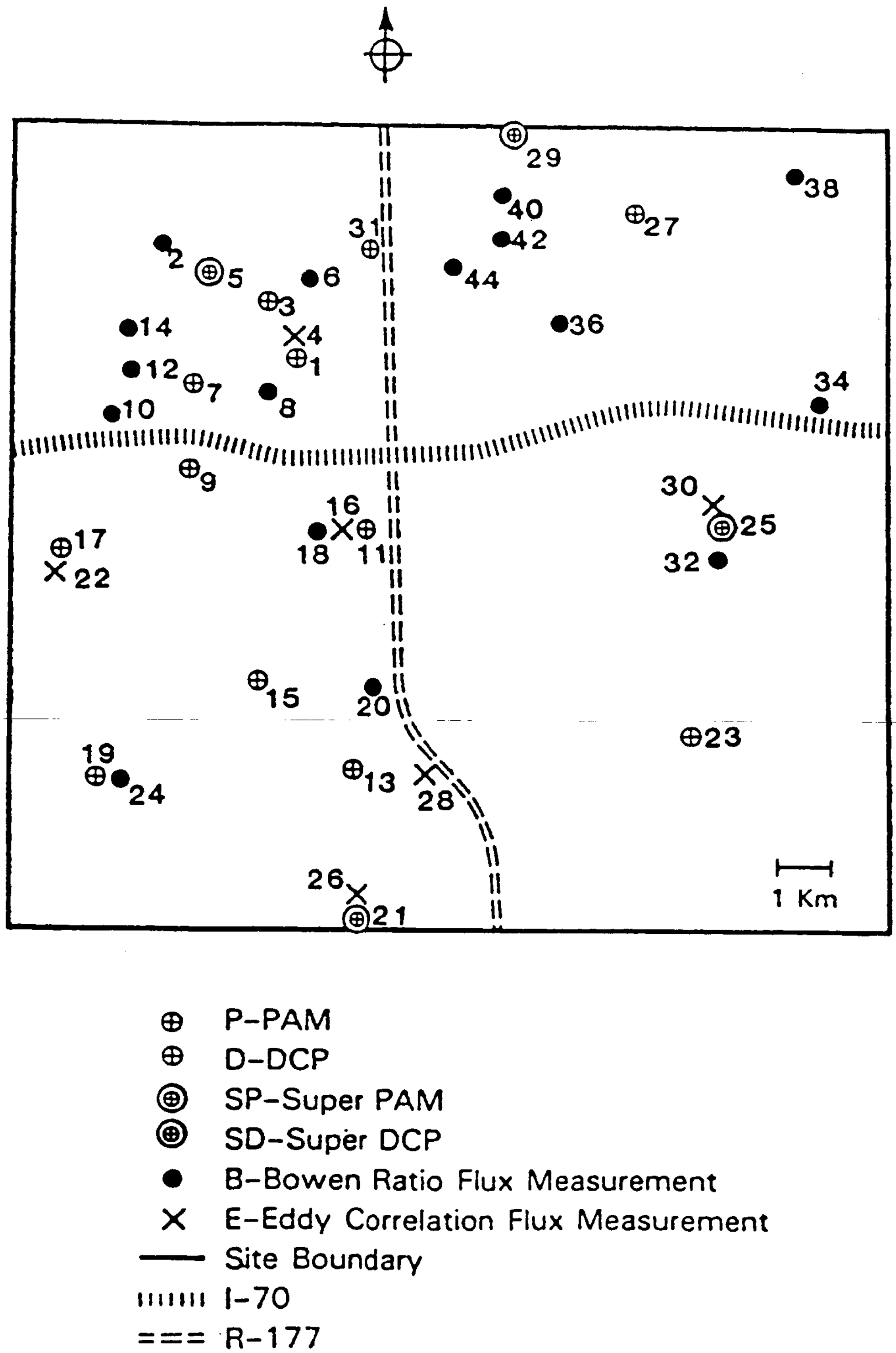


Figure 2.1. Map of FIFE site showing the Flux Station and Automatic Meteorological Station locations by station site number.

Table 1. Site characteristics.

Characteristic	Site					
	20	34	36	40	42	44
UTC nor.	431554	4327081	4328767	4331670	4331122	4329981
UTC eas.	712977	720917	716069	714225	714109	713616
Latitude	39 01 07	39 03 59	39 04 58	39 06 34	39 06 17	39 05 40
Longitude	96 32 24	96 26 48	96 30 07	96 31 21	96 31 26	96 31 48
Elevation	415	414	368	410	410	420
Slope, deg.	7	10	3	7	5	0
Aspect, deg.	242	123	122	180	35	
Treatment	burned	burned	unburned	burned	burned	burned

control, raw data were averaged at 6 minute intervals and recorded on 200 kbyte floppy disks at 6 minute intervals.

The computer was programmed so that the field operator could review the instantaneous data (sampled at 30-s intervals) in raw form or in engineering units using a single keyboard command. In addition, a third keyboard command displayed calculated values of the energy budget components, computed and updated at 6 minute intervals, and a fourth display contained the instantaneous, present 6-minute, past 6-minute and 12 minute averages of the temperatures and the temperature differences.

Raw data was written on a 200 kbyte 3 1/2 in. floppy disks. The floppy will hold eight days of data (17 channels + 2 date time groups) stored as 6 min. averages. Primary power was supplied by a 12 Vdc deep cycle RV battery.

Each **SERBS** was powered by a 12 volt deep cycle RV battery which was charged by a 12 W solar panel. Each system had an additional battery for voltage reference. The total power consumption was 2796 mW of which 1200 mW was consumed by the psychrometer fans.

The computer, data system, floppy disk drive and reference battery were housed in a 40 quart food cooler which was covered with a space blanket. This was done to keep the computer at a reasonably constant temperature; in addition the space blanket was used to keep liquid water out of the cooler.

3.2. Sensors

The variables measured consisted of: air and wet bulb temperatures at two heights; net, solar (up and down), total hemispherical (up and down); diffuse radiation; soil heat flow and soil temperature; wind speed and wind direction and precipitation.

Ceramic wick psychrometers mounted on an **AEM** were used to obtain the gradients of air and wet bulb temperatures. Sensitivity and similarity of temperature sensors is required for the **EBM** method. Platinum resistance elements (**PRTD**) (500 ohms) were used for the temperature sensors.

The temperature sensitivity of the **PRTD**, with 0.5 mA current, is 1.0 mV $^{o}C^{-1}$ which is equivalent to 0.005 ^{o}C on our data system (Fritschen and Simpson, 1982). The four temperature sensors are connected in series to insure that the same current is flowing through the sensors. In addition, the voltage drops across the **PRTD**'s are measured using a common offset voltage equal to the mid-range temperature.

Soil heat flux density was measured at 5 cm with three heat flow transducers (Radiation and Energy Balance Systems, HFT-1). The 0 to 5 cm soil temperature was measured with three 100 ohm **PRTD**'s connected in series. The temperature sensitive area was 8 cm in length and the sensors were inserted in the soil at a 45^{o} angle.

Net and total hemispherical radiation (up and down) were measured with double dome instruments from Radiation and Energy Balance Systems, Q-3 and THRDS-1. Double dome net and total hemispherical radiometers were used because the error due to convective heat loss from the transducer is greatly reduced. Net radiometers with thin signal domes tend to indicate to large of an outgoing nocturnal flux.

Solar radiation was measured with Kipp and Zonen pyranometers, CM-2, while diffuse solar radiation was measured with a Licor pyranometer, LI-200SB, mounted in a shadow band.

Wind speed and direction were measured with R. M. Young instruments (12004).

Precipitation was determined with tipping bucket rain guages of several makers.

In addition, a copper-constantan thermocouple was inserted to 0.5 m at each site to provide soil temperature. The thermocouple was read manually each time the site was serviced.

The height of sensor mounting is given in the documentation file for each IFC data file located in the data bank.

3.4 System calibration

The ADC-1's and the offset voltages were calibrated using a precision potentiometric bridge with 1 microvolt resolution, and an absolute accuracy of ± 0.02% of the reading ± 1 digit (Electro Scientific Industries model 300PVB). The ADC-1 low gain was calibrated using potentiometer of the ADC-1 and the ESI as a precision voltage source set to 150 mV. All systems were adjusted to read 1500 (3000 for systems 2 and 3) raw A/D units. The standard deviation of 10 readings was 0 units. Once this was set, high gain was selected and calibrated with the input set at 15 mV. All systems were adjusted to read 3000 raw A/D units. The standard deviation of 10 readings was ± 0.7 units.

The temperature coefficients of the ADC-1 and the constant current sources were investigated. With the critical components of the ADC-1 being replaced with low coefficient components, the temperature coefficient of the ADC-1 was found to be 8 ppm $^{o}C^{-1}$ over a range of -25 to +35 ^{o}C. The temperature coefficient of the constant current sources was found to be 7.3 x 10^{-9} A $^{o}C^{-1}$, or 15 ppm $^{o}C^{-1}$, over the temperature range from 0 to 55 ^{o}C, and 15 x 10^{-9} A $^{o}C^{-1}$, or 30 ppm $^{o}C^{-1}$, over the temperature range from -25 to 55 ^{o}C.

3.5 Sensor Calibration

All of the sensors were calibrated before the measurement period began. The net radiometers, total hemispherical radiometers and heat flow transducers were also calibrated after the measurement period. Little change was noted in the calibrations.

Table 4.1 Input file for system 1, site 44.

M	N1	N2	N3	N4	N5	N8	GO	M7
19,	6,	30,	1,	15,	3,	2,	2,	17
LG	HG	HOME	REF	O1	O2	RC	NCRTD	
9.99,200.6, 7,			0,	265.02,160.05,.50051,9				
DELZ ELEV CSOIL			DZ	REF	HOME			
1.00,420, 1.5,			.05,	0,	7			

CN	RG	GAIN	BIAS	TYPE	DESC.	Ser. No.
1,	2,	26.77,	0,	4	G	16
2,	0,	11.20,	0,	4	Q	Q87053
3,	2,	82.13,	0,	4	Kdn	3750
4,	2,	82.92,	0,	4	Kup	3701
5,	2,	153.39,	0,	4	D	1577
6,	0,	8.87,	0,	4	Qdn	T87011
7,	2,	1.00,	0,	6	Home	
8,	0,	3.4904,	0,	3	Udir	#1 Gill
9,	1,	500.095,	0,	2	Tab	81 3/4
10,	1,	500.098,	0,	2	Twb	81 5/6
11,	1,	500.012,	0,	2	Tat	82 3/4
12,	1,	500.065,	0,	2	Twt	82 5/6
13,	3,	299.590,	0,	2	Ts	300PT86
14,	0,	100,	0,	2	Tq	T87011
15,	0,	0.1987,	0.7,	4	U	#1 GILL
16,	2,	8.87,	0,	4	Qup	T87011
17,	0,	2.54,	0,	5	P	GUAGE
INDAT1.DO				13:32 2/29/87		

4. SOFTWARE DESCRIPTION

Two categories of software will be considered. The first consists of programs written for the NEC personal computers that were used for field data acquisition, and data acquisition system testing. The second consists of a series of programs used for post-experimental data processing, including energy and radiation balance calculations, plots and printed summaries used in this report.

Listings of some of the programs are given in Appendix 9 because the software contains documentation of the procedures used in analyzing the data. All software is still in the development stages, and as such is not free from errors, nor have all the refinements been incorporated to make their operation "user friendly". This is especially true of the auxiliary, supporting software. However, based on the excellent field performance of the primary data acquisition and processing program SAMP.BA, it is felt that the software is basically sound.

4.1 Data acquisition (SAMP.DO, INDATx.DO)

Data acquisition and field procession was controlled by program SAMP.BA, a BASIC program written for the NEC portable computer. This program, listed in Appendix 9.1, is

Table 4.2 Input file for system 2, site 34.

```
M      N1     N2     N3     N4     N5     N8     G0     M7
19,    6,     30,    1,     6,     3,     2,     2,     17
LG     HG     HOME   REF    O1     O2     RC     NCRTD
20.00,199.93,7,  0,     259.72,160.11,.50023,9
DELZ ELEV CSOIL  DZ     REF    HOME
1.00,292, 1.5,   0.05,  0,     7
CN  RG   GAIN      BIAS TYPE DESC.  Ser. No.
1,  0,  33.75,      0,   4   G      26
2,  0,  11.00,      0,   4   Q      Q87052
3,  0,  12.10,      0,   4   Kdn    P87008
4,  0,  11.50,      0,   4   Kup    P87008
5,  0,     .1325, 0.2,   4   U      GILL
6,  0,  11.50,      0,   4   Qdn    T87014
7,  2,    1.00,     0,   6   Home
8,  0,    1.989,    0,   3   Udir   83 Gill
9,  1, 500.692,     0,   2   Tab    81 3/4
10, 1, 499.903,     0,   2   Twb    81 5/6
11, 1, 499.852,     0,   2   Tat    82 3/4
12, 1, 499.536,     0,   2   Twt    82 5/6
13, 3, 299.966,     0,   2   Ts     300PT86
14, 0, 100,         0,   2   Tq     T87014
15, 0, 100,         0,   2   Tp     P87008
16, 2,  11.60,      0,   4   Qup    T87014
17, 0,   2.54,      0,   5   P      GAGE
INDAT2.DO                11:48 2/29/87
```

largely self documenting. Statements 1000 to 1192 constitute the main program, with control of subroutine calls routed through a jump table in lines 100 to 300.

The program is customized for a particular location, system, and set of sensors through the use of an input file named "INDATx.DO", where x was an identifier set equal to the particular system number. Files INDAT1.DO through INDAT9.DO for the six systems used in the present experiment are listed in Tables 4.1 to 4.6. Control parameters set by files INDATx.DO are partially identified in lines 1, 3 and 5, and the last two columns of the actual file, or by comparison with program lines 9110-9195 where the data is read by SAMP.BA. A description of these identifiers is found in Table 4.7.

The psychrometer separation and site elevation are included in the INDAT files. A standard atmosphere (101.3 kPa) is assumed in the calculation of atmospheric pressure (P), which is then corrected for altitude using a lapse rate of -0.01055 kPa m^{-1}.

4.2 Test Programs (ADCTST.BA)

A program was developed for use in testing the operation of the data acquisition system, ADCTST.BA. The ADCTST.BA (9.2) uses the built-in serial port driver. Communication with the ADC-1 from a BASIC program via the standard serial port driver uses INP and OUT statements.

Table 4.3 Input file for system 3, site 42.

```
M      N1     N2     N3     N4     N5     N8     G0     M7
19,    6,     30,    1,     6,     3,     2,     2,     17
LG     HG     HOME   REF    O1     O2     RC     NCRTD
19.96,198.45,7,      0,     264.84,161.11,.50053,9
DELZ ELEV CSOIL  DZ     REF    HOME
1.00,410, 1.5,  0.05,  0,     7
CN  RG   GAIN      BIAS TYPE DESC. Ser. No.
1,  2,  31.05,      0,   4   G      36
2,  0,  10.90,      0,   4   Q      Q87059
3,  0,  86.40,      0,   4   Kdn    P87007
4,  0,  44.20,      0,   4   Kup    P87007
5,  0,    .1290,   .2,   4   U      GILL
6,  0,   9.42,      0,   4   Qdn    T87013
7,  2,   1.00,      0,   6   Home
8,  0,   1.989,     0,   3   Udir   83 Gill
9,  1, 499.580,     0,   2   Tab    81 3/4
10, 1, 499.563,     0,   2   Twb    81 5/6
11, 1, 499.851,     0,   2   Tat    82 3/4
12, 1, 500.041,     0,   2   Twt    82 5/6
13, 3, 300.71,      0,   2   Ts     300PT86
14, 0, 100,         0,   2   Tq     T87013
15, 0, 100,         0,   2   Tp     P87007
16, 0,   9.70,      0,   4   Qup    T87013
17, 0,   5.08,      0,   5   P      GAGE
INDAT3.DO                13:33 2/29/88
```

Table 4.4 Input file for system 7, site 36.

M	N1	N2	N3	N4	N5	N8	G0	M7
19,	6,	30,	1,	6,	3,	2,	2,	17
LG	HG	HOME	REF	O1	O2	RC	NCRTD	
9.994,193.33,7,			0,	264.41,160.40,.49925,9				
DELZ	ELEV	CSOIL	DZ	REF	HOME			
1.00,368, 1.5,			0.05,	0,	7			

CN	RG	GAIN	BIAS	TYPE	DESC.	Ser. No.
1,	2,	27.05,	0,	4	G	76
2,	0,	11.00,	0,	4	Q	Q87058
3,	2,	80.88,	0,	4	Kdn	773743
4,	2,	80.45,	0,	4	Kup	773741
5,	2,	88.90,	0,	4	D	6712
6,	0,	7.22,	0,	4	Qdn	T87012
7,	2,	1.00,	0,	6	Home	
8,	0,	3.856,	0,	3	Udir	83 Gill
9,	1,	499.888,	0,	2	Tab	81 3/4
10,	1,	500.107,	0,	2	Twb	81 5/6
11,	1,	500.035,	0,	2	Tat	82 3/4
12,	1,	499.961,	0,	2	Twt	82 5/6
13,	3,	300.24,	0,	2	Ts	300PT86
14,	0	100,	0,	2	Tq	T87012
15,	0,	0.1957,	0.7,	4	U	GILL
16,	0,	7.36,	0,	4	Qup	T87012
17,	0,	2.54,	0,	5	P	GAGE
INDAT7.DO				13:32 2/29/88		

4.3 Data transfer (LapDos)

The software used for reading floppy disks into an AT compatible computer was called LapDos. The LapDos operated a spare floppy disk drive which was attached to the serial port of the AT like any other floppy drive. The station day files were transferred to 5 1/4 floppies for archiving.

4.4 Post Experimental Data Processing and Data Conversion From Raw to Engineering Units (SAMPR1.BAS and SAMPR2.BAS)

The second series of programs were developed for initial post-experimental data processing, including energy and radiation balance calculations. They are coded in Microsoft BASIC 5.2, and were intended to be compiled and run using the Microsoft BASIC compiler to reduce execution time. The data conversion and energy/radiation balance processing are based in part on the field sampling and analysis program SAMP.BA (Section 4.1).

All programs are controlled by an input file named

Table 4.5 Input file for system 8, site 20.

```
M      N1     N2     N3     N4     N5     N8     G0     M7
19,    6,     30,    1,     6,     3,     2,     2,     17
LG     HG     HOME   REF    O1     O2     RC     NCRTD
10.0,199.97,7,       0,     264.44,160.40,.499595,9
DELZ ELEV CSOIL     DZ     REF    HOME
1.00,415, 1.5,      0.05,  0,     7
CN   RG    GAIN      BIAS  TYPE DESC.   Ser. No.
1,   2,   34.32,      0,    4   G       86
2,   0,   11.30,      0,    4   Q       Q87057
3,   2,   84.36,      0,    4   Kdn     838771
4,   2,   85.09,      0,    4   Kup     838751
5,   2,   92.49,      0,    4   D       6710
6,   0,    8.33,      0,    4   Qdn     T87015
7,   2,    1.00,      0,    6   Home
8,   0,    1.752,     0,    3   Udir    83 Gill
9,   1, 499.284,      0,    2   Tab     81 3/4
10,  1, 499.337,      0,    2   Twb     81 5/6
11,  1, 499.956,      0,    2   Tat     82 3/4
12,  1, 499.890,      0,    2   Twt     82 5/6
13,  3, 300.63,       0,    2   Ts      300PT86
14,  0, 100,          0,    2   Tq      T87015
15,  0,   0.2149,   0.1,    4   U       83 FRIT
16,  0,    8.66,      0,    4   Qup     T87015
17,  0,    2.54,      0,    5   P       GAGE
INDAT8.DO                  13:32 2/29/88
```

PDS.FIL which contains values of certain control parameters, an identification label, and a list of file names to be processed (Table 4.8). The meaning of the control parameters varies, depending on exact program involved.

Systems 2 and 3 did not have a diffuse radiometer, consequently the wiring configuration was slightly different from the other systems. Therefore, the analysis program SAMPR1 was modified for systems 2 and 3. This program is called SAMPR2. In operation, after the day files listed under SAMPR1 in the PDS.FIL are processed, the program chains to SAMPR2.

The ASCII raw data files were edited using a text editor so that each contained one day's data for one data system, starting and ending at 0000 hours. Since an average was stored every 6 minutes during data collection, each file contains a maximum of 241 records. Using this data as input, SAMPR1.BAS (Appendix 9.3) converts the raw data (in A/D units) to engineering units (.g. oC, m s-1, etc.). System and time specific data is found in lines 9300 - 9400, lines 6300 - 6400 (analogous to lines 9000-9106 and 9110 to

Table 4.6 Input file for system 9, site 40.

```
M      N1     N2     N3     N4     N5     N8     G0     M7
19,    6,     30,    1,     6,     3,     2,     2,     17
LG     HG     HOME   REF    O1     O2     RC     NCRTD
10.0,200.03,7,       0,     259.77,159.96,.500008,9
DELZ ELEV CSOIL  DZ      REF    HOME
1.00,315, 1.5,  0.05,    0,     9
CN   RG   GAIN      BIAS TYPE DESC.  Ser. No.
1,   2,   23.88,     0,   4   G      96
2,   0,   11.50,     0,   4   Q      Q87061
3,   2,   82.15,     0,   4   Kdn    001
4,   2,   82.55,     0,   4   Kup    60294
5,   2, 167.90,      0,   4   D      1579
6,   0,   11.70,     0,   4   Qdn    T87017
7,   2,    1.00,     0,   6   Home
8,   0,    1.129,    0,   3   Udir   83 Gill
9,   1, 500.002,     0,   2   Tab    81 3/4
10,  1, 500.502,     0,   2   Twb    81 5/6
11,  1, 500.103,     0,   2   Tat    82 3/4
12,  1, 500.287,     0,   2   Twt    82 5/6
13,  3, 300.382,     0,   2   Ts     300PT86
14,  0, 100,         0,   2   Tq     T87017
15,  0,    0.0891, 0.1,   4  U      83 FRIT
16,  2,   11.70,     0,   4   Qup    T87017
17,  0,    2.54,     0,   5   P      GAGE
INDAT9.DO                 12:02 5/12/87
```

Table 4.7. Description of INDATx.DO control files used in program SAMP.BA.

M Total number of variables in each data record

N1 Minutes in each averaging period (between Bowen ratio interchanges)

N2 Number of seconds between samples (0 < N2 < 59)

N3 Maximum number of records allowed in memory storage buffer (calculated in program line 9265)

N4 Minutes between data output to cassette tape (Changed in the program into N4/N1, which is the number of data records written to the cassette each access).

N5 Number of times each analog channel is sampled before the value is saved. This allows for a longer settling time for the A/D converter when sampling low level signals using the on board amplifier.

N8 Number of minutes samples are not taken after the Bowen ratio interchange device has operated to allow temperatures to come into equilibrium.

G0 Not used

M7 Total number of analog and digital inputs being sampled (M7 = M - 2; 2 variables are used to store date and time).

LG Gain of low range (mv/AD unit)

HG Gain of high range (mv/AD unit). Selected by adding 32 to the channel number.

HOME Channel number of AEM Home signal.

REF Channel thermocouple reference connected to (not currently in use)

O1 Offset #1 (mv). Selected by adding 16 to the channel number.

O2 Offset #2 (mv). Selected by adding 48 to the channel number.

RC(1) Value of constant current through dry and wet bulb resistance temperature elements (ma).

NCRTD Channel number of the first resistance temperature element

CHAN C(K) Array of channel numbers

RANGE C1(K) 0 = Lo gain, adding 0 to chan. no.
1 = Hi gain, offset 1, adding 16 to chan. no.
2 = Hi gain, no offset, adding 32 to chan. no.
3 = Hi gain, offset 2, adding 48 to chan. no.

GAIN G(K) mv gain (eng. units/mv)

BIAS B(K) bias (eng. units)

TYPE N(K) 1 = type K thermocouple
2 = resistance temperature element
3 = wind direction
4 = linear calibration
5 = digital input
6 = Home signal

DESC. X$ Used in data file for description only

In addition, the following quantities are calculated in connection with the above control parameters.

G2(K) mv gain for each channel

B1(K) offset for each channel (if used, otherwise zero)

C1(K) This is converted to the actual channel number plus
the offset for use in the A/D routine

NRTD The number of resistance temperature elements

NWD not used

NDIG number of digital channels

NANLG number of analog channels

9195 in SAMP.BA) and lines 6200-6300. The identical files used in the field analysis (Tables 4.1 to 4.6) are used with this program.

The data is stored in a text file for summarizing and further analyses using a spread sheet SMART. A series of SMART projects were developed to compute half hour averages and daily summaries of all of the variables, to compute means and standard deviations among the sites, to plot various variables, and to make data bank files. These SMART projects are batch processed under control of an executive project which loads each day file and calls the other projects.

Table 4.8. Sample contents of control file PDS.FIL.

```
SAMPR1
0,0,0,C:,C:,.MF,P
Konza Prairie; eng units conversion (SAMPK2  6/14/85 1423)
R8080187,R8080287,R8080387,R8080487,R8080587,R8080687
END
SAMPR2
0,0,0,C:,C:,.MF,P
Konza Prairie; eng units conversion (SAMPK2  6/14/85 1423)
R3080187,R3080287
END
```

5. SYSTEM PERFORMANCE

During intensive campaigns, the sites were serviced daily if weather permitted. Between the intensive campaigns, the sites were serviced weekly. A total of 876 station days or 3,994,560 data points were possible during the recording period. Data gaps amounted to 14% of the time if total or part days were counted as missing days. About 5 % of the data gaps can be filled in by completing the part days. Four percent of the data gaps were due to batteries running down while about 3 % of the data were lost due to failure of either the floppy disk or the drives. This data loss probably would be reduced by using a computer with built in 720 kbyte floppy drive. One microcomputer failed and most of the remaining data gaps occurred at site T44. It is worthy to note that each exchange mechanism cycled more than 35,000 times without failure. A listing of the days with part or all data missing by system number in Table 5.1.

Recommendations for improvements in the **SERBS** performance include the following:

(1) replace the NEC computers and floppy drives with laptop computers containing more reliable floppy drives;
(2) increase the size of the solar panels to 40 or 50 W;
(3) increase the psychrometer ventilation rate and radiational shielding; and
(4) install a float reservoir on the psychrometer in place of the constant head device.

The **SERBS** could operate for two week periods with the above improvements. All things considered, the systems operated better than expected for continuous data collection. Only one wire was chewed by a rodent and one anemometer had to be replaced.

6. RESULTS

Most of the time since the field season has been spent in editing the data files and creating files for the data bank. At present, selected variables for the four IFC's have been submitted to the data bank. Additional time is required for further checking of the remaining variables. The data for the periods between the IFC's has been processed but required further quality control before submission to the data bank.

A preliminary comparison of net radiation for a clear day early in the season is given in Figure 6.1. Even though the sites are as much as 16 km apart and represent the four cardinal slopes, there is an amazing uniformity of measured net radiation. One can notice that the east facing slope appears to have a phase lag of a few minutes compared to the other sites.

Table 5.1. Days when data for part or all of the day were missing for each data system.

		Site								Site					
MODA	DOY	44	34	42	36	20	40	MODA	DOY	44	34	42	36	20	40
526	146	H	X	H	X			708	189						
527	147		X		X			709	190						
528	148		H		X			710	191						
529	149				H			711	192						
530	150		H					712	193						
531	151		H				H	713	194	H					
601	152						H	714	195	X					
602	153	H						715	196	H					
603	154	H						716	197						
604	155							717	198						
605	156			H				718	199						
606	157							719	200						
607	158							720	201						
608	159							721	202	X					
609	160							722	203	X					
610	161							723	204	X					
611	162							724	205	H					
612	163							725	206						
613	164							726	207						
614	165		H	H	H			727	208						
615	166	H	H		H			728	209						
616	167	H						729	210						
617	168							730	211						
618	169							731	212						
619	170	X						801	213						H
620	171	X						802	214						X
621	172	X						803	215						H
622	173	X						804	216	H					X
623	174	X						805	217	X			H		X
624	175	X						806	218	H			H		X
625	176	H						807	219				H		X
626	177							808	220				H		H
627	178	H						809	221						
628	179	X						810	222						
629	180	H		H				811	223						
630	181	H		X				812	224						
701	182			H				813	225					X	
702	183						H	814	226						
703	184			H				815	227						
704	185			X				816	228						
705	186			X				817	229						
706	187			H				818	230						
707	188							819	231						

Table 5.1 Cont. Days when data for part or all of the day are missing for each data system.

		Site								Site					
MODA	DOY	44	34	42	36	20	40	MODA	DOY	44	34	42	36	20	40
820	232							918	261	H		H			
821	233							919	262	X					
822	234							920	263	X					
823	235							921	264	X					
824	236							922	265	X					
825	237							923	266	H					
826	238							924	267	H					
827	239							925	268	H					
828	240							926	269	X			H		
829	241							927	270	X			X		
830	242							928	271	H			H		
831	243							929	272	H					
901	244							930	273	X					
902	245							1001	274	X				X	
903	246							1002	275	H				X	
904	247					H		1003	276	X				X	
905	248					H		1004	277	X				H	
906	249					X		1005	278	H				H	
907	250					X		1006	279					H	
908	251					X		1007	280	H					
909	252				H	H		1008	281	H		H			
910	253				X		H	1009	282	H		H			
911	254				X		X	1010	283						
912	255			H	X		X	1011	284						
913	256	H		X	X		X	1012	285	H					
914	257	H		H	H		H	1013	286	H					
915	258							1014	287	H					
916	259							1015	288						
917	260			H				1016	289						

X indicates data missing
H indicates part of data missing

A comparison of the air temperature (1 m above the surface) is given in Figure 6.2. During the daylight hours, the air temperature was very uniform. Note that the east facing slope (E34) had a slightly lower temperature in the late afternoon hours that the other sites. The standard deviation was less than 0.5 ^{o}C. Again this result is quite remarkable considering the distance between sites, the condition of the surface at each site and the fact that 12 temperature sensors and 6 data systems are involved in the comparison. Part of the uniformity may be ascribed to the fact that the wind speed was about 5 m s^{-1}. At night, the variation in air temperature was a little larger, possibly due to differences in cold air drainage at the sites.

Site differences begin to emerge in comparison of the air vapor pressures, Figure 6.3. The south facing slope (S40) has the lowest vapor pressure during the day. The standard deviation among sites was less than 0.005 kPa during most of the day and approached 0.007 at 1430.

Site differences become larger with the comparison of soil heat flux density (to be referred to as soil heat flow), Figure 6.4. The sites having the best vegetative cover (N42 and W20) have to lowest soil heat flow during the day. The two east facing sites (E34 and E36) had the greatest soil heat flow. At E34, about 20 % of the surface was exposed rock. Both sites had the least amount of vegetation. The maximum standard deviation was 100 W m^{-2} at midday.

Latent heat flux densities for the sites are shown in Figure 6.5. The latent heat flux density was the largest at W20. This site appeared to be an anomaly for a west facing site. It had the best vegetative cover possibly due to seepage from the limestone rock layer. Note the sharp rise of evaporative rate at W20 about 0700 and the sharp decrease in evaporative rate at E34 about 1800. These values are associated with periods of positive sensible heat flux density. Site E34 had the lowest evaporative rate during the morning hours. At this time, a large number of rocks were exposed at the surface. Later in the season, most of the smaller rocks were covered by the grass.

The sensible heat flux densities were rather small, less than 150 W m^{-2} , Figure 6.6. The largest sensible heat fluxes were observed at sites E34 and S40 while the smallest sensible heat flux occurred at W20. The two peaks of positive sensible heat flux (about 0700 at W20 and 1800 at E34) occurred when the radiant flux on the slopes was low.

The Bowen ratios for the sites are shown in Figure 6.7. During the daylight hours, these ratios were quite small being about 0.2. A period of large Bowen ratios occurred at E34 between 0700 and 1000.

The values of the energy balance, during the periods of positive net radiation, were accumulated for the period from May 26 to October 16. Missing data were filled in using ratios with other systems. The accumulated daylight net radiation totals are amazingly similar, Figure 6.8. The average was 1947 MJ (m2 period)$^{-1}$ with a standard deviation of $\pm$ 22, Table 6.1. The daily average was 13.5 $\pm$ 0.15 MJ (m2 period)$^{-1}$.

The accumulated soil heat flux illustrated the character of the sites, Figure 6.9. The trends which were established early in the season persisted throughout the season. The north facing slope had the lowest soil heat flux while E36 had the highest heat flux.

Similar trends were noted in the latent heat flux density plot, Figure 6.10. W20 and N42 had the largest latent heat flux densities while E34 and E36 had the lowest.

Table 6.1. Energy balance values (accumulated or averaged for 144 days) at six sited during FIFE, 1987.

	Aspect and Site Number							
Value	T44	E34	N42	E36	W20	S40	Ave.	STD.
	<---------------- MJ $(m^2$ period$)^{-1}$ ---------------->							
Q*	13.44	13.40	13.59	13.62	13.77	13.31	13.52	0.15
G	-0.43	-1.28	-0.09	-0.73	-0.19	-0.29	-0.50	0.40
E	-10.11	-10.11	-10.75	-9.72	-11.22	-10.31	-10.37	0.49
H	-2.90	-2.82	-2.75	-3.43	-2.36	-2.71	-2.83	0.32
	<-------------------- Ratio ---------------------->							
β	0.29	0.28	0.26	0.35	0.21	0.26	0.27	0.04
$\frac{E}{Q^*+G}$	-0.78	-0.83	-0.80	-0.75	-0.83	-0.79	-0.80	0.03
	<-------------------- mm m^{-2} ---------------------->							
E/L	-4.16	-4.16	-4.43	-4.00	-4.62	-4.24	-4.27	0.20

The average for the period was -1493 ± 70 MJ $(m^2$ period$)^{-1}$ or -615 ± 29 mm. This amounts to a daily average of -10.37 +_0.49 MJ (m2 period)$^{-1}$ or + 4.27 ± 0.2 mm day^{-1}.

Accumulated heat flux densities were small, Figure 6.11. Site W20 had a slight positive sensible heat flux for the first 55 days. On the other hand, E36 had the largest sensible heat flux density. This site had the least and shortest vegetative cover. The average of the accumulated heat flux density was -408 ± 46 MJ $(m^2$ period$)^{-1}$. The daily average was -2.83 ± 0.32 MJ $(m^2$ period$)^{-1}$.

Small positive Bowen ratios occurred during most of the season. After a long dry period, the Bowen ratios increased rather sharply day 270). These values give rise to average Bowen ratio of 0.27 ± 0.04.

The percent of the available energy converted to latent heat flux density is a more conservative index than the Bowen ratio. For the period of this experiment, about 80 % of the available energy was converted to evaporative flux.

7. SUMMARY AND CONCLUSIONS

Six automatic Surface Energy and Radiation Balance Systems were operated continuously for 146 days from May 25 to October 16, 1987 as part of the **FIFE** project. A total of 17 variables were monitored at each site. Calculations of the surface sensible and latent heat flux densities were made using the energy balance method.

Preliminary results indicate that variables including net radiation, air temperature, vapor pressure and wind speed were quite similar for the sites even though the sites were as much as 16 km apart and represented the four cardinal slopes and a top. Daily average net radiation was 13.52 ± 0.15 MJ $(m^2 \text{ period})^{-1}$. The largest percentage differences between sites occurred in soil heat flux density, (-0.50 ± 0.40 MJ $(m^2 \text{ day})^{-1}$.

The latent heat flux density averaged -10.37 ± 0.49 MJ $(m^2 \text{ day})^{-1}$ or -4.27 ± 0.20 mm day^{-1}. The accumulated amount was -615 ± 29 mm.

The Bowen ratio was low during most of the season increasing sharply toward the end of the season after a long dry spell. The average Bowen ratio was 0.27. About 80 % of the available energy was converted into latent heat flux density.

Figure 6.1. Comparison of net radiation at six sites on 6 June 1987.

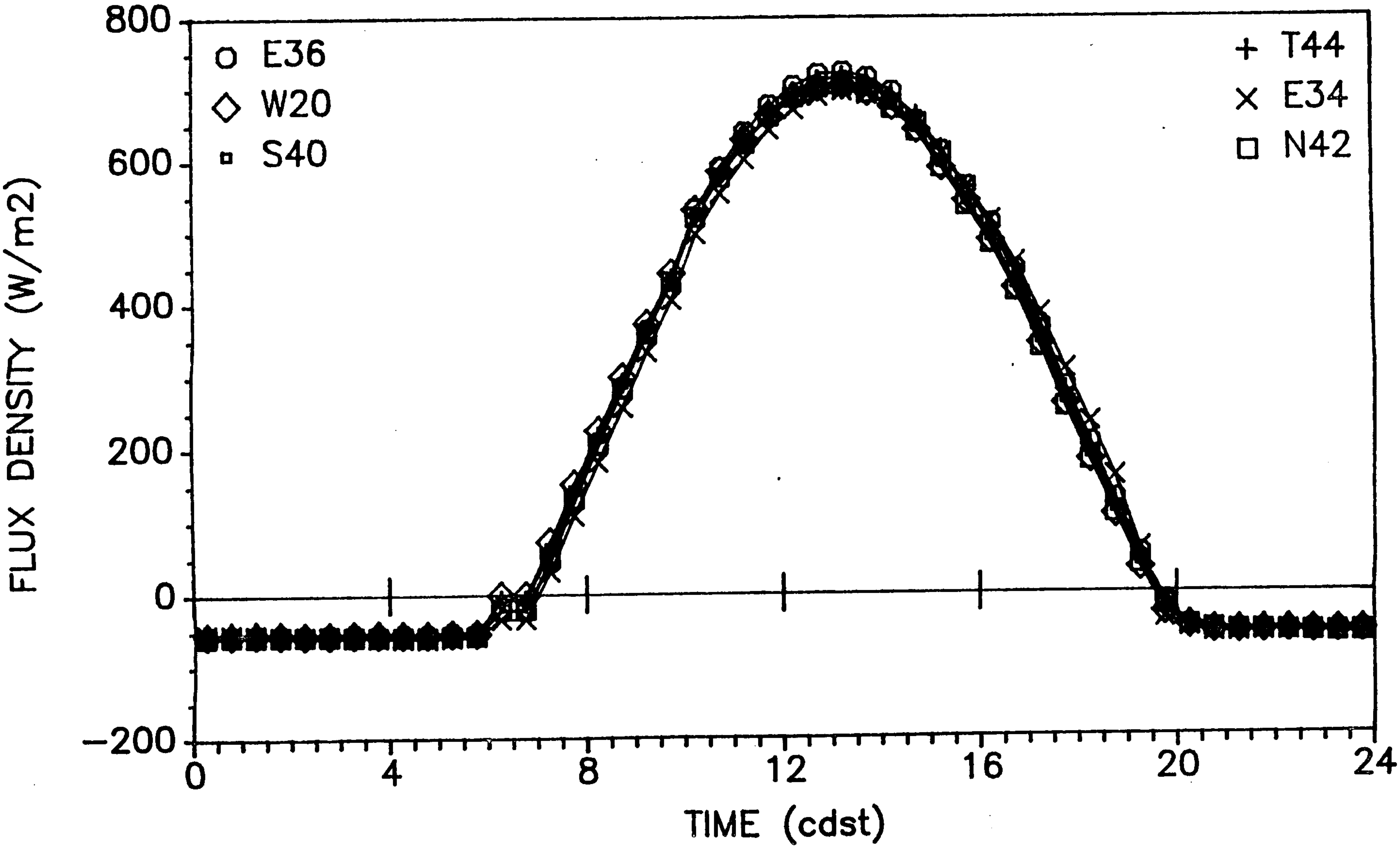


Figure 6.2. Comparison of air temperature at six sites on 6 June 1987.

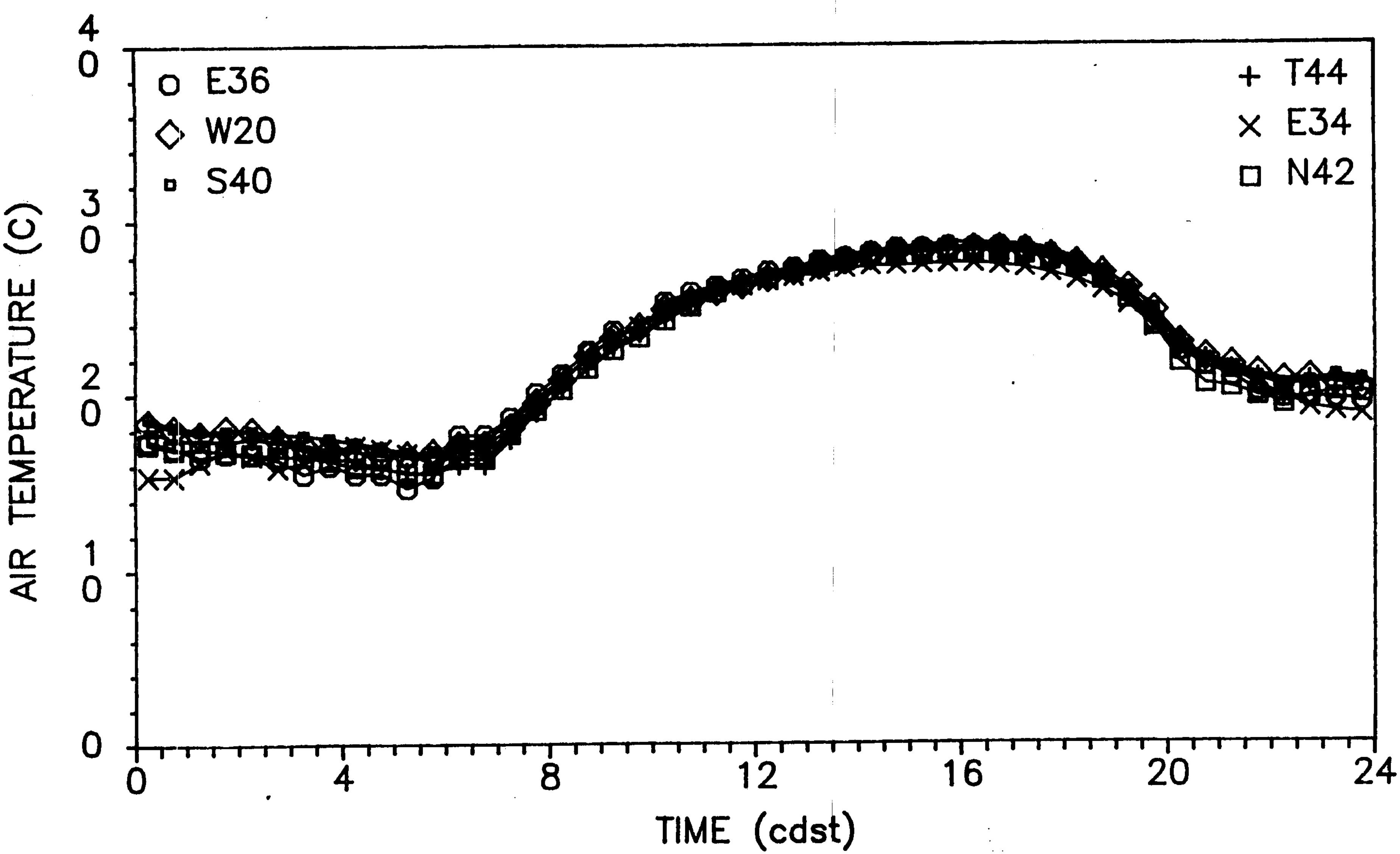


Figure 6.3. Comparison of air vapor pressure at six sites on 6 June 1987.

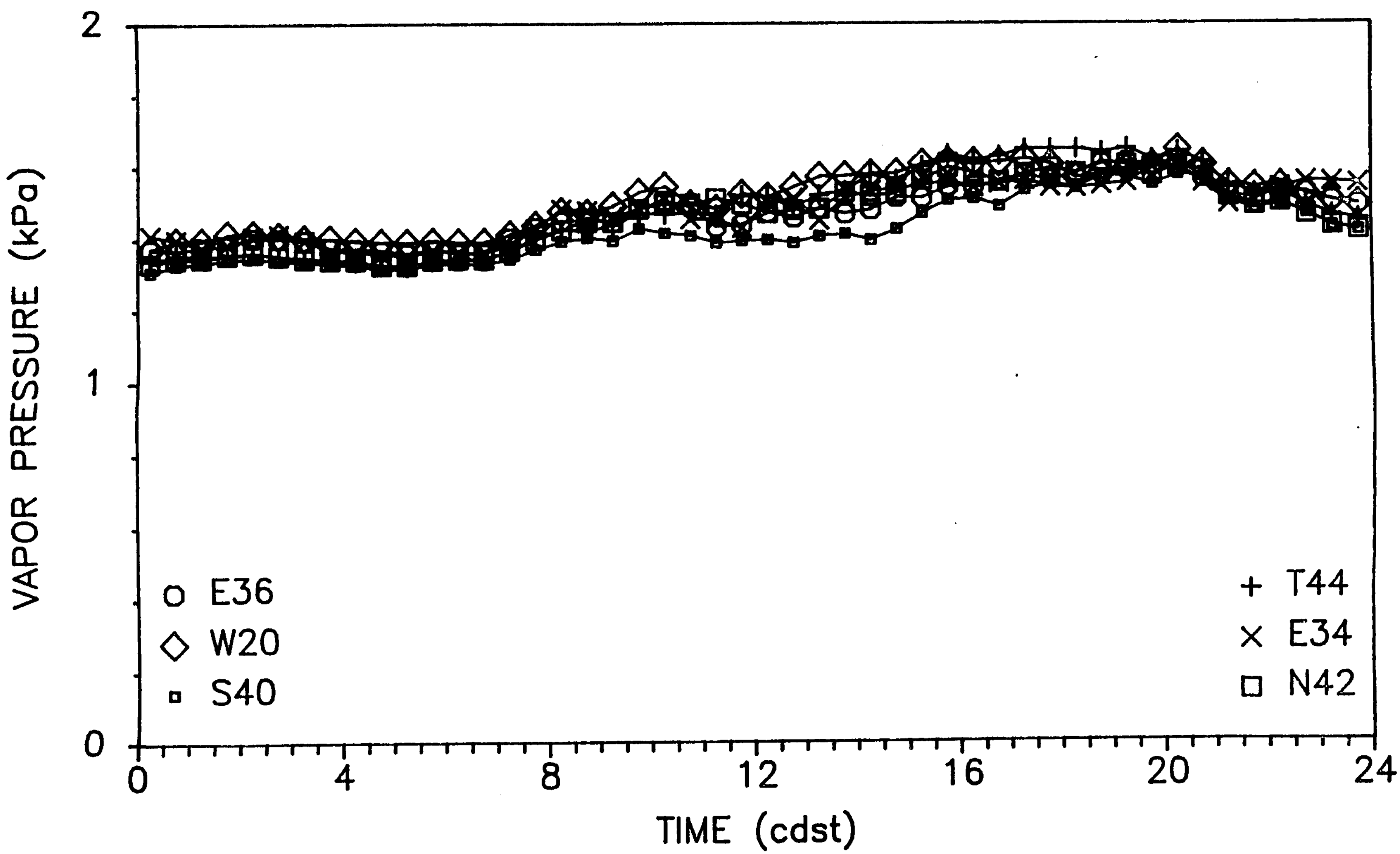


Figure 6.4. Comparison of soil heat flux density at six sites on 6 June 1987.

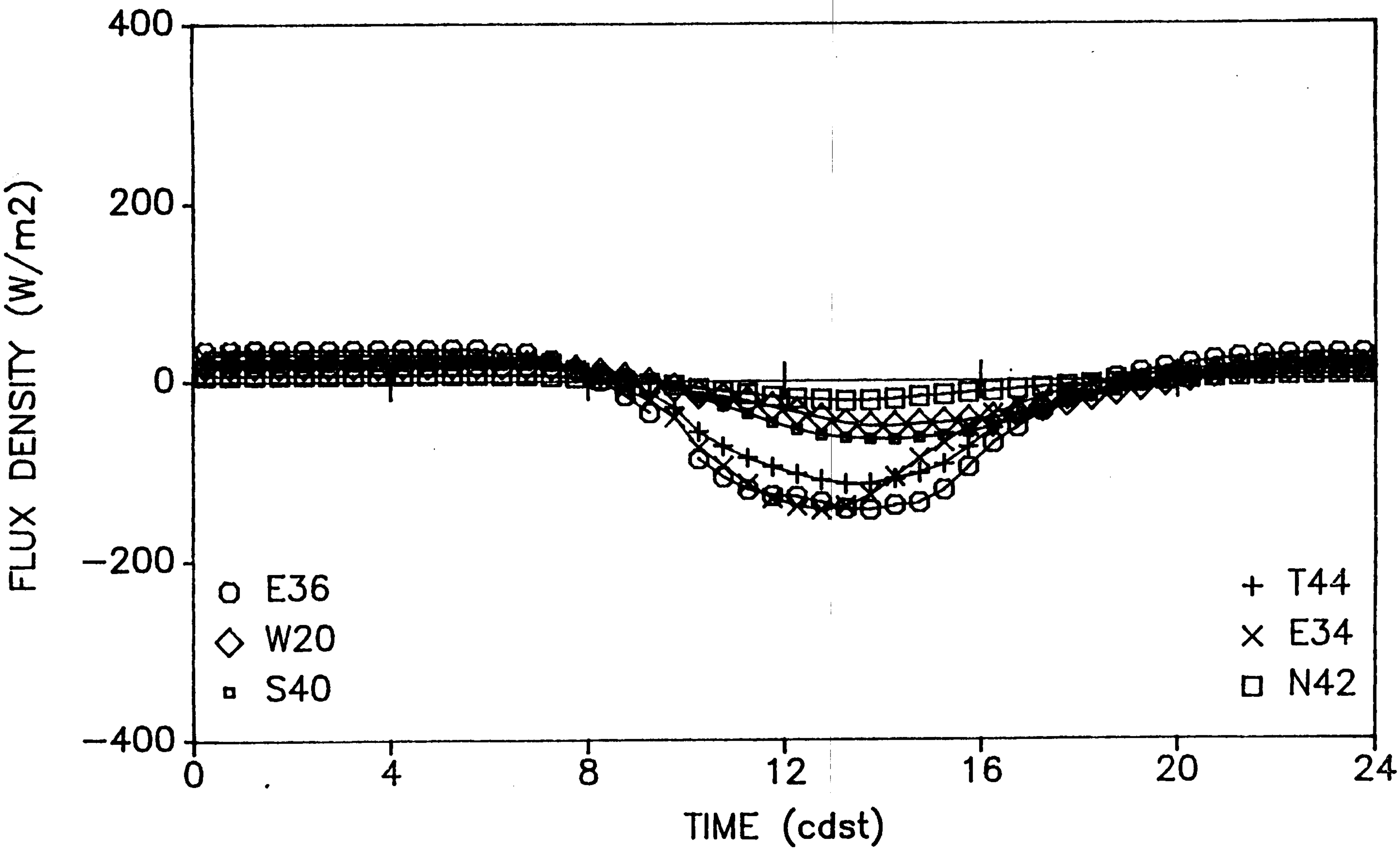


Figure 6.5. Comparison of latent heat flux density at six sites on 6 June 1987.

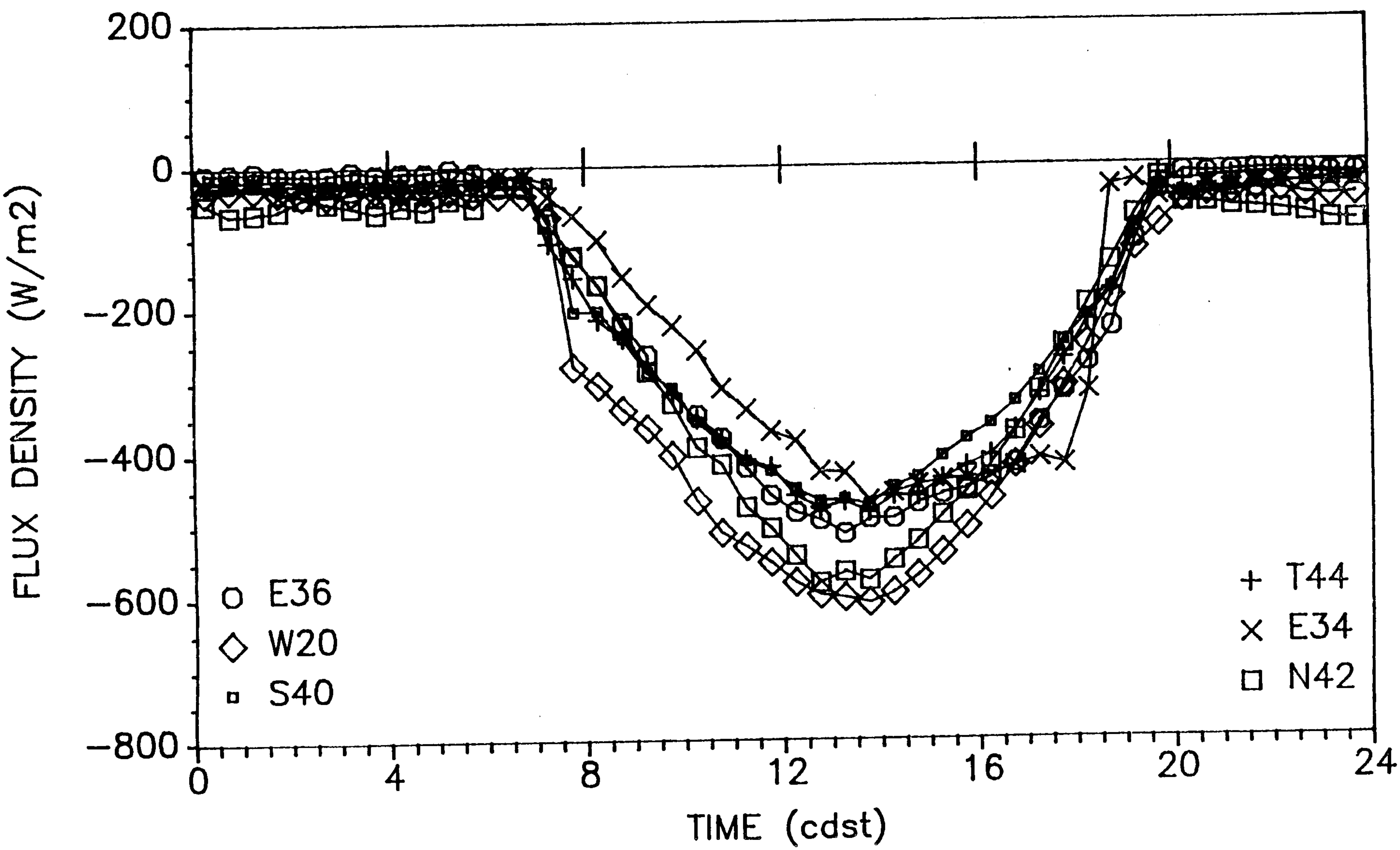


Figure 6.6. Comparison of sensible heat flux density at six sites on 6 June 1987.

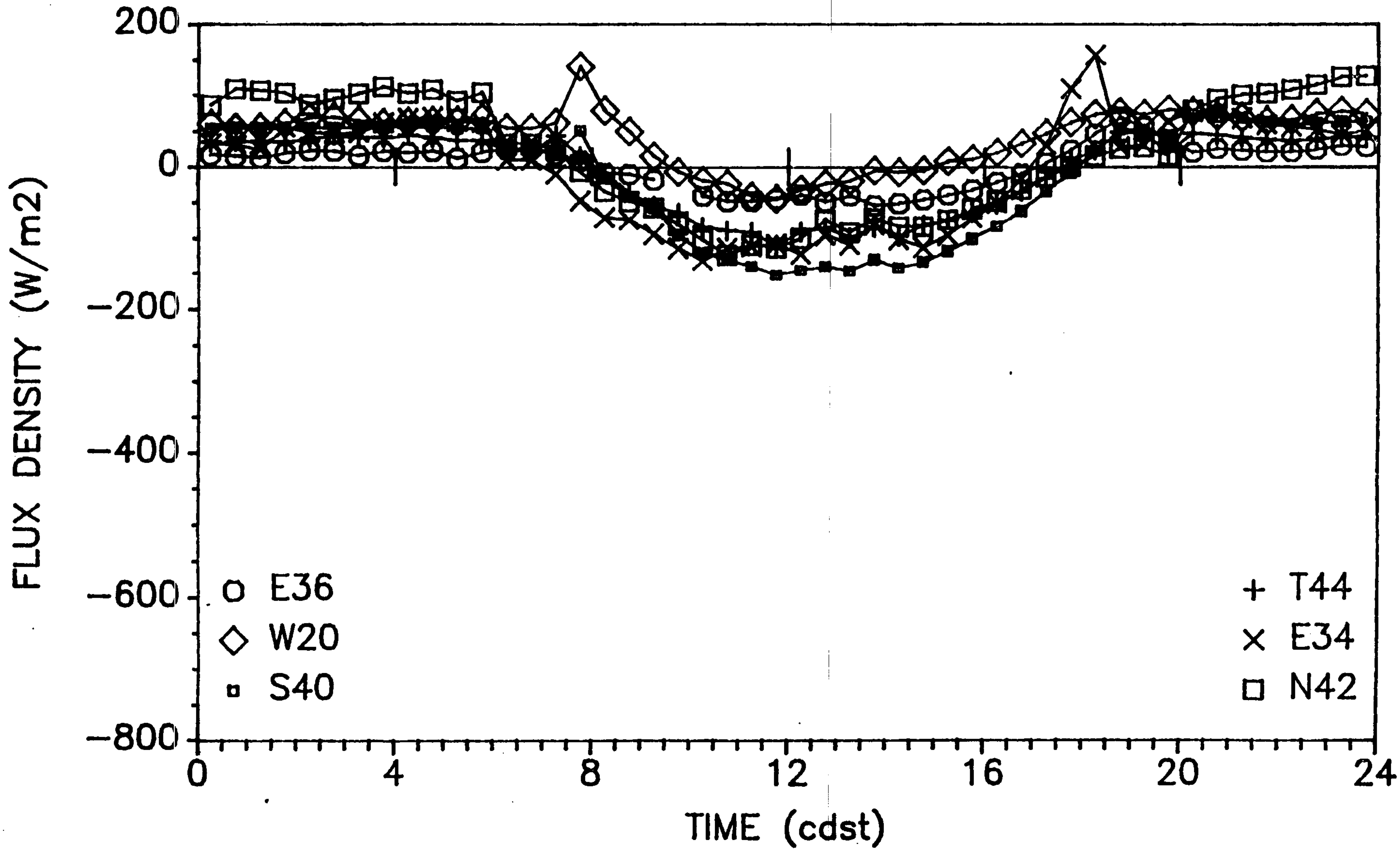


Figure 6.7. Comparison of Bowen ratio at six sites on 6 June 1987.

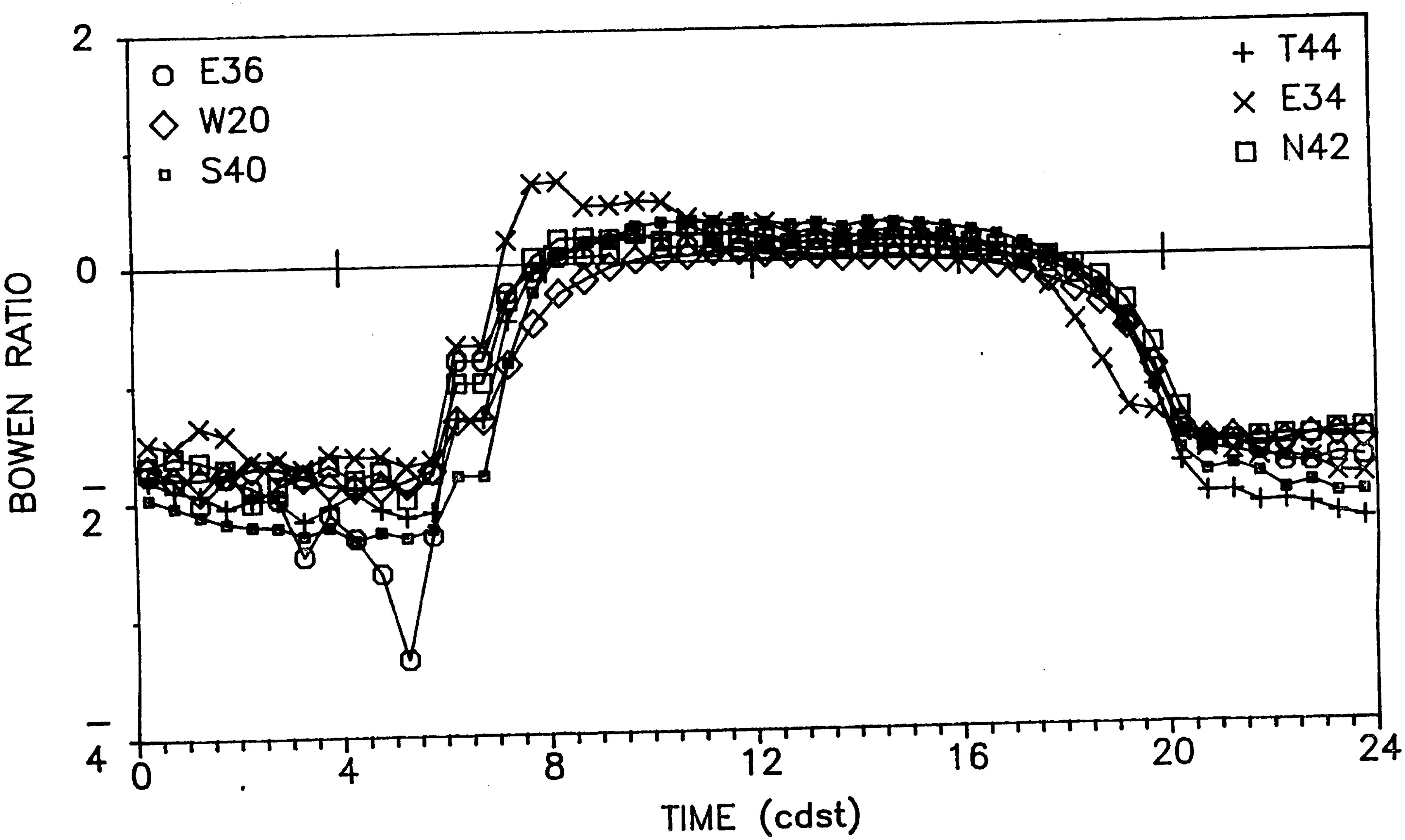


Figure 6.8. Net radiation at six sites accumulated from 25 May (day 145) till 16 Oct. 1987 (day 289).

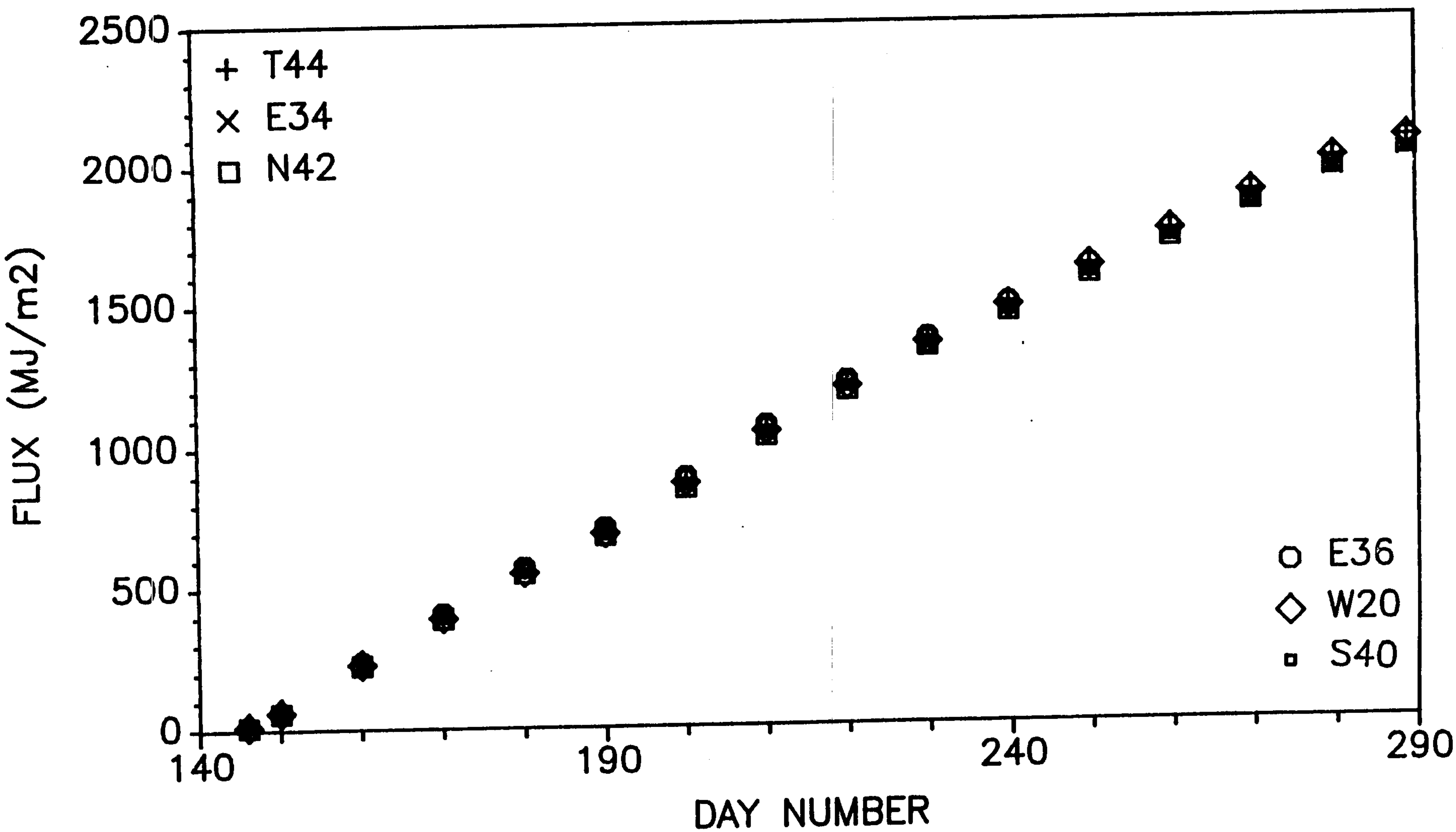


Figure 6.9. Soil heat flux density at six sites accumulated from 25 May (day 145) till 16 Oct. 1987 (day 289).

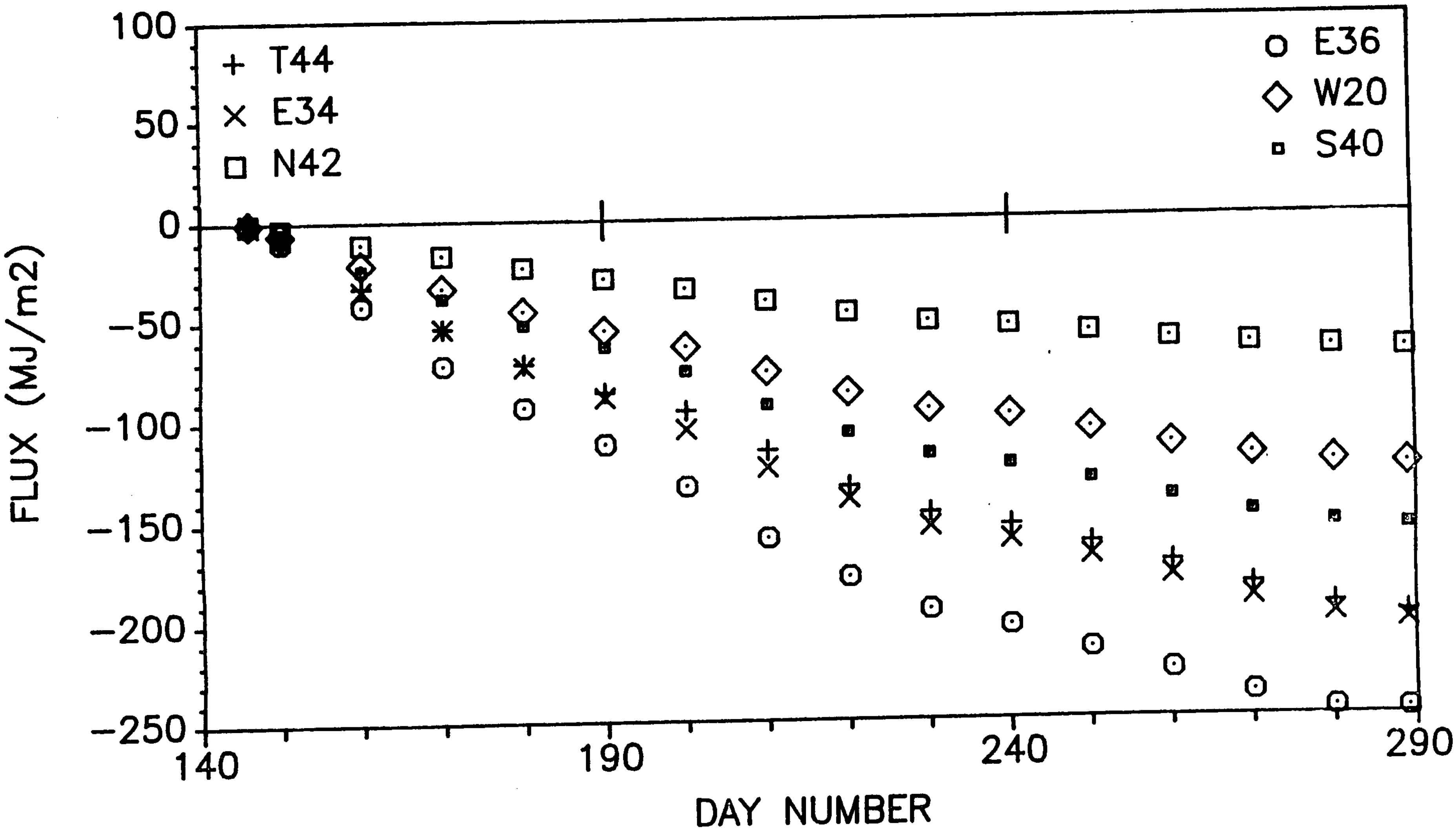


Figure 6.10. Latent heat flux density at six sites accumulated from 25 May (day 145) till 16 Oct. 1987 (day 289).

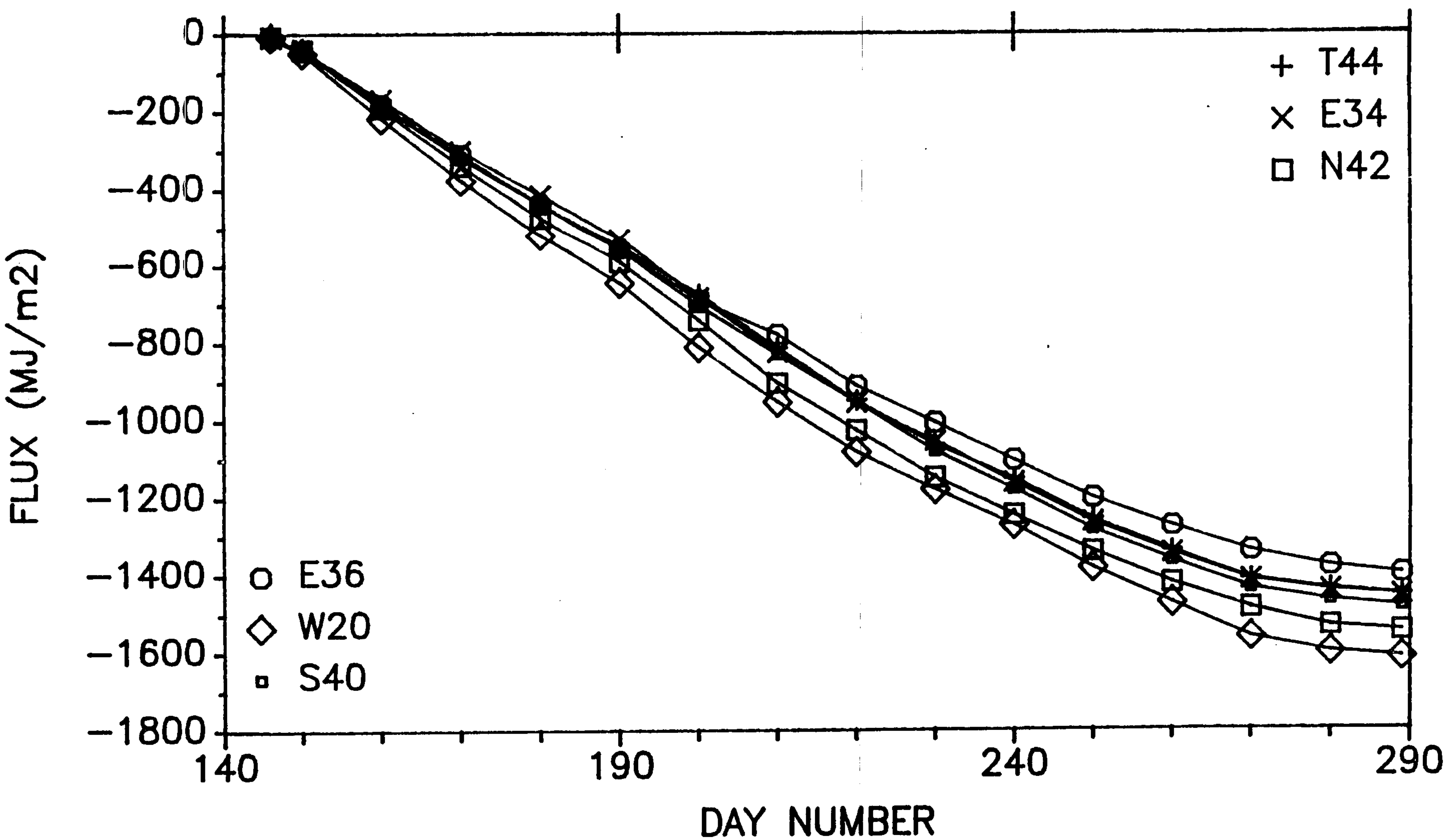


Figure 6.11. Sensible heat flux density at six sites accumulated from 25 May (day 145) till 16 Oct. 1987 (day 289).

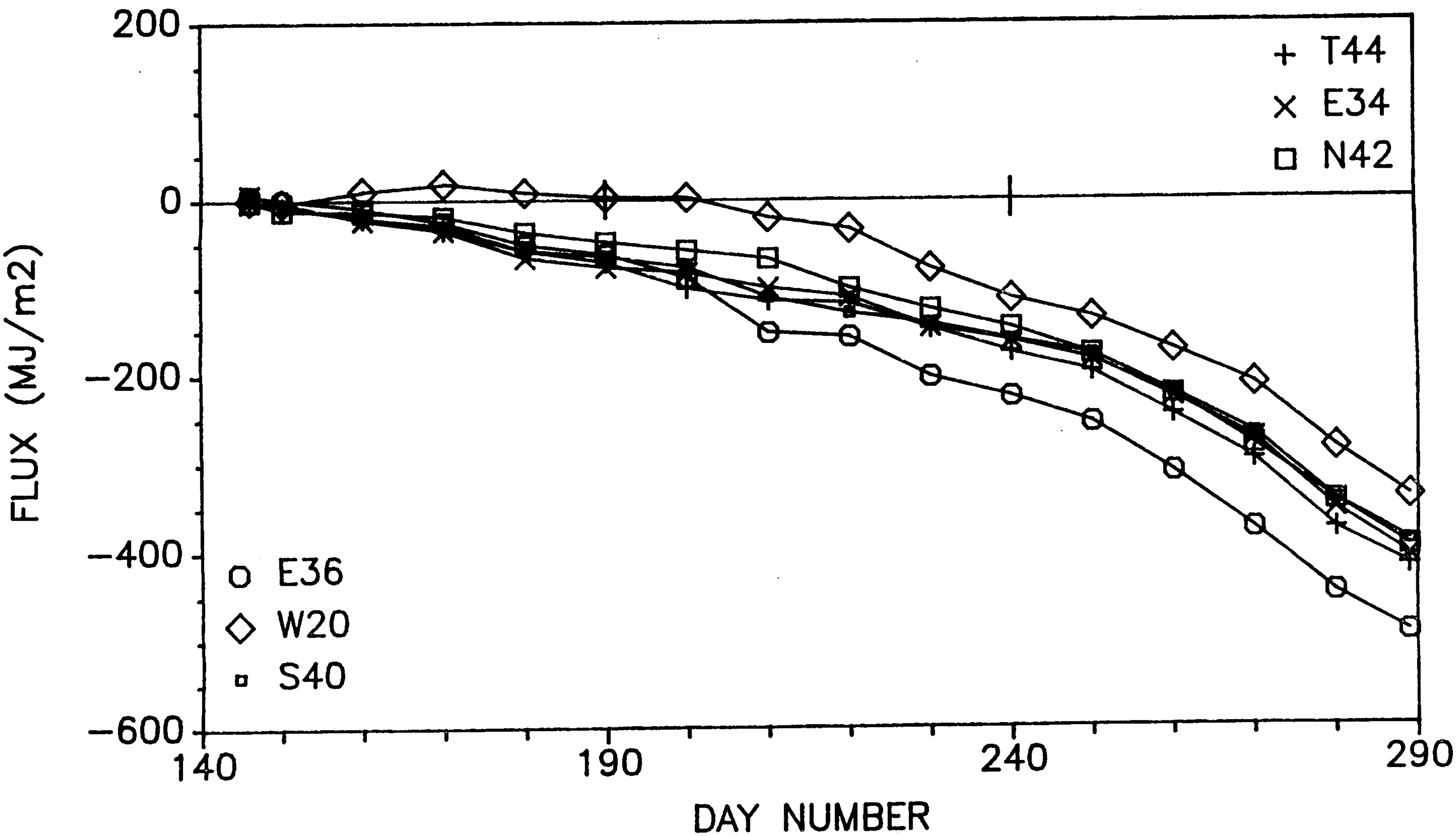
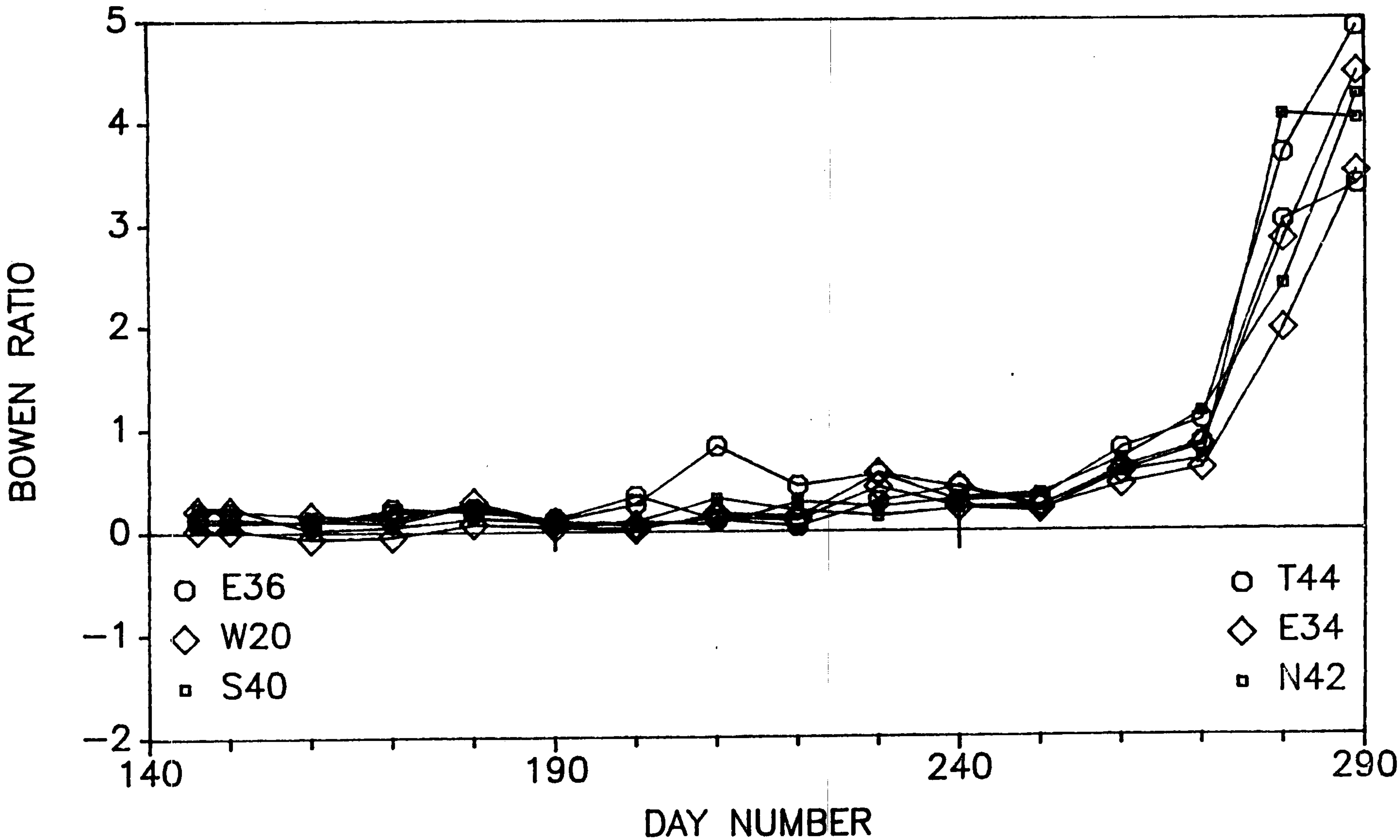


Figure 6.12. Bowen ratio at six sites accumulated from 25 May (day 145) till 16 Oct. 1987 (day 289).



8.1 LITERATURE CITED

Fritschen, L. J. and J. R. Simpson. 1982. An automatic system for measuring Bowen ratio gradients using platinum resistance elements. 739-742. In: Temperature, its Measurement and Control in Science and Industry. Vol. 5. James F. Schooley, ed. Am. Institute of Physics.

Fritschen, L. J., L. W. Gay, and J. R. Simpson. 1983. The effect of a moisture step change and advective conditions on the energy balance components of irrigated alfalfa. 83-86. In: Extended Abstracts. 16th Conference on Agric. and Forest Meteor. Apr. 26-28, 1983. Ft. Collins, CO. Am. Meteorol. Soc.

8.2 MANUSCRIPTS PREPARED

Fritschen, L. J. and Ping Qian. 1988. Energy balance components at six sites. Not submitted for publication.

Fritschen, L. J. and J. R. Simpson. 1988. Surface energy and radiation balance systems. Submitted to J. Appl. Meteor.

9. APPENDICES

9.1 SAMP.BA, A sampling program for the NEC computer.

```
10 ' Program SAMP8.BA for nec 8201 AND ADC-1, 4/27/87 1423
25 ' For NASA 87 field experiment (this version does use
     digital inputs & TANDY DISK DR)
26 ' Calcs for bidirectional THR's
45 MAXFILES=3
50 CLS:SCREEN 0,0
55 DEFINT I-N
60 GOSUB 115:GOSUB 116
98  '
99      GOTO 1000        ' * * *  TO START OF PROGRAM * * *
100 '
105 '                    JUMP TABLE
110 '
115   GOTO 9000  ' INITIALIZE
116   GOTO 2100  ' MISC. CONSTANTS
120   GOTO 500   ' CLOCK
125   GOTO 300   ' SCREEN OUTPUT
130   GOTO 400   ' E/RAD BALANCE OUTPUT
135   GOTO 600   ' TC; MV TO C
140   GOTO 700   ' SAMPLE A/D (3000)
145   GOTO 800   ' GET DIGITAL INPUTS
150   GOTO 900   ' A/D TO MV CONVERSION
155   GOTO 1300  ' VECTOR WIND DIR.
160   GOTO 1500  ' RTD, MV TO C
165   GOTO 1600  ' DIGITAL OUTPUT
170   GOTO 1700  'BREB
175   GOTO 1900  ' RADIATION BALANCE
180   GOTO 9100  ' CONTROL PARAMETERS
185   GOTO 9200  ' CALIBRATION FACTORS
190   GOTO 2000  ' MISC. FUNCTIONS
195   GOTO 950   ' A/D UNITS TO MV
200   GOTO 12000 ' ERROR TRAPPING
205   GOTO 2200  ' DISK DR
207   GOTO 1200  ' AUDIO CASSETTE DUMP
210   GOTO 2500  ' PRINTER OUTPUT
220   GOTO 2700  ' GRADIENT DISPLAY
290 ' - - - - - - - - - - - - - - - - - -
300 '
301 '  DISPLAY SUMMARY
302 '
305 CLS:LOCATE 0,1
310 IF DSP THEN MCOL=4 ELSE MCOL=3
315 FOR I=1 TO MCOL
316 IF DSP THEN PRINT "CHAN RAW "; ELSE PRINT "CHAN   ENG";
317 NEXE:PRINT
320 FOR K=1 TO M7 STEP MCOL
322  FOR K=I TO MCOL+I-1
323    IF K>M7 THEN 335
325      IF DSP THEN 326 ELSE 328
326      PRINT USING "## ##### ";C(K);A(K);:GOTO 330
```

```
328      PRINT USING "###
     #####.###";C(K);A(K);INT(1000*A1(K))/1000
330    NEXT:PRINT
335  NEXT
350 'RETURN
400 '     DISPLAY ENERGY, RAD BALANCE
405 CLS:GOSUB 120
407 LOCATE 0,2
410 PRINT "      H       E       B       Q       G"
415 PRINT USING F1$;H;E;B;Q;G+GF1
420 PRINT "    KDN     KUP     LUP     LDN     Qerror"
430 PRINT USING F2$;KDN;KUP;LUP;LDN;Q5-QN
435 PRINT "      TT      TWT     E       DT      DE"
450 PRINT USING F3$;T9;W9;E9;DT;DE;
455 LOCATE 0,0:PRINT "      U       DIR     Gp"
460 PRINT USING F2$;A1(17);A1(8);GF1;
470 RETURN
500 '  CLOCK - HOURS/MINUTES/SECONDS  (HR/MIN/SEC)
501 '
502 SEC=VAL(MID$(TIME$,7,2))
505 IF S8=59 AND SEC=0 THEN 590
510 IF S8<>SEC THEN 515 ELSE RETURN
515 LOCATE 23,1
520 PRINT TIME$;" ";DATE$;
522 DSP$=INKEY$:IF DSP$="" THEN 575
525 IF DSP$=CHR$(27) THEN E2=1 ' ESC?
533 IF DSP$="R" THEN DSP=1:GOSUB 125
534 IF DSP$="E" THEN DSP=1:GOSUB 125
535 IF DSP$="C" THEN GOSUB 130
540 IF DSP$="P" THEN PRT=1
545 IF DSP$="O" THEN PRT=0
550 IF DSP$="G" OR DSP$="H" THEN GOSUB 220
575 S8=SEC
580 HR=VAL(MID$(TIME$,1,2))
585 YR=VAL(MID$(DATE$,9,2)) : MO=VAL(MID$(DATE$,1,2)) :
     DA=VAL(MID$(DATE$,4,2))
590 MIN=VAL(MID$(TIME$,4,2)):RETURN
600 '
605 '    THIS SUBROUTINE CONVERTS READINGS FROM A
     THERMOCOUPLE AND
610 '    REFERENCE JUNCTION IN A/D UNITS TO DEG. C.
615 '
625   V=A1(IC) + A1(REF)
627   A1(IC)=B1*V+B2*V^2+B3*V^3+B4*V^4
640   RETURN
700 '
704 '   ***  SAMPLE A/D (ADC-1); CONVERT TO DECIMAL  ***
705 '
707 GOSUB 9300
710 FOR K2=1 TO NANLG:CN=C1(K2)
715  FOR I1=1 TO N5
725   OUT PN, CN                          '    SELECT CHANNEL;
     START A/D
```

```
730   X=INP(PN)                              '     GARBAGE
     CHARACTER
735   OUT PN,129+32                          '     GET ADC-1 HIGH
     BYTE/STATUS
745   HBYTE=INP(PN)                          '     SAVE HIGH BYTE
     FROM A/D
750   IF(HBYTE AND 128) <> 0 THEN 735        '     CHECK STATUS
     FOR A/D FINISHED
755   OUT PN,129+16                          '     GET ADC-1 LOW
     BYTE
765   LBYTE=INP(PN)                          '     SAVE LOW BYTE
     FROM A/D
770   HMASK=HBYTE AND 15                     '     MASK 4 HIGH
     ORDER BITS FROM A/D
775   Y=LBYTE+256*HMASK                      '     COMBINE ALL 12
     BITS FROM A/D
780   IF (HBYTE AND 16)=0 THEN Y=-Y          '     FIX SIGN IF
     NEGATIVE FLAG SET
782   IF I1=N5 THEN 785 ELSE 787
785   A(K2)=Y
787  NEXT
790 NEXT:RETURN
800 '
801 '    ***  SAMPLE AND RESET COUNTERS  ***
802 '
805 GOSUB 9300
810 X=INP (PN):'CLEAR PORT
815 OUT PN,129:'REQ DATA
820 FOR J = 0 TO 50 :NEXT
825 CHIN=INP (PN):D=CHIN AND 15
827 OUT PN,128:'RESET INPUTS
830 FOR I=1 TO NDIG:DTEST=2^(I-1)
835 IF DTEST AND D THEN CO(I)=1
840 A(NANLG+I)=A(NANLG+I)+CO(I):CO(I)=0
845 A1(NANLG+I)=A(NANLG+I)*G(NANLG+I)
850 NEXT
860 RETURN
900 '
901 '  A/D UNITS TO MV
905 '
910 FOR I=1 TO NANLG
915   A1(I)=A(I)*G2(I)+B1(I)
925 NEXT
940 RETURN
949  '
950  ' MV TO ENG. UNITS, LINEAR
951  '
960  A1(IC)=A1(IC)*G(IC)+B(IC)
970  RETURN
1000 '
1005 ' MAIN SAMPLING LOOP
1010 '
1015 LOCATE 24,30:PRINT "WAIT FOR SECONDS = 0  ";
1020 GOSUB 120:IF SEC>2 THEN 1020
```

```
1025 GOSUB 120:IF SEC=0 THEN 1025
1030 LOCATE 24,50:PRINT "SAMPLING INITIATED    ":'ON ERROR
     GOTO 12000 '   ????
1032 J9=0:POKE I1,0:POKE I2,0:POKE I3,0
1035 J9=J9+1:N6=0:H9=0:LOCATE 18,1:PRINT J9
1040   FOR K1=1 TO M : D(K1)=0 : A2(K1)=0 : NEXT
1045   A1=0:A2=0 ' ZERO VECTOR COMPONENTS OF WIND DIRECTION
1050   GOSUB 120
1052   IF INT(SEC/N2)<>SEC/N2 THEN 1050  '  UPDATE CLOCK
     TILL TIME TO SAMPLE
1055     GOSUB 145 '  SAMPLE COUNTERS
1060     GOSUB 140 '         SAMPLE A/D'S
1065     IF INT((MIN+N1-1-N8)/N1)<>INT((MIN+N1-1)/N1) THEN
     LOCATE 1,1:PRINT "WAIT FOR EQUILI.      ":GOTO 1050 '
     SKIP 1ST N8 POINTS
1068     GOTO 1085 '    SKIP HOME CHECK
1070     IF ABS(A(HOME)) >400 THEN 1085
1075    IF INT(MIN/N1)=MIN/N1 THEN 1085
1080     H9=H9+1:IF H9<=2 THEN 1050
1085     N6=N6+1
1087     GOSUB  150  '  A/D UNITS TO MV
1090     FOR IC=1 TO NANLG
1093       D(IC)=D(IC)+A(IC)     ' SUM RAW DATA
1095       ON N(IC) GOSUB 135,160,155,195,195
1100       A2(IC)=A2(IC)+A1(IC)    ' SUM ENG UNITS
1110     NEXT
1120     GOSUB  125  '  UPDATE DISPLAY
1125     LOCATE 23,1:PRINT "SAMPLE BELOW
     SAVED=";J9;"N6=";N6;
1130     GOSUB  120  '   GET TIME
1135     IF E2=1 THEN 1145 ' EXIT IF "ESCAPE" LAST KEY
     PRESSED
1140     IF INT(MIN/N1)=MIN/N1 AND SEC+N2>59 THEN 1142 ELSE
     1050
1142 '
1145   IF N6<10 THEN I=N6 ELSE I=0
1146   DS%(J9,M-1)=HR*1000!+MIN*10+I    '  HRS/MIN
1150   DS%(J9,M)    = MO *100 + DA
1151 FOR I=1 TO NDIG
1152 DS%(J9,NANLG+I)=A(NANLG+I):A2(NANLG+I)=0:A(NANLG+I)=0:
1153 NEXT
1155   GOSUB  165  '  REVERSE BOWEN RATIO DEVICE
1160   FOR I=1 TO NANLG
1165     A2(I)=A2(I)/N6
1170     IF N(I)<> 3 THEN DS%(J9,I)=D(I)/N6 ELSE
     DS%(J9,I)=D(I)
1175   NEXT
1180   J=NCRTD:K9=1:IF TPE <>1 THEN GOSUB 170 ' BREB
1182   IF PRT=1 THEN GOSUB 210   '  PRINTER OUTPUT
1185   IF E2=1 THEN STOP
1190   IF MIN MOD N4*N1=0 THEN GOSUB 205
1191   IF J9>=N3 THEN J9=0
1192 GOTO 1035
1195 '
```

```
1200 '
1205 '
1210 IS=J9-N4+1:IE=J9:TPE=0:IF IS<1 THEN IS=1
1300 '
1305 '    VECTOR AVG WIND DIRECTION
1315 '
1330 A7=(A1(IC)*G(IC)+B(IC))/DPR
1340 A1=A1+COS(A7):A2=A2+SIN(A7)
1345 IF A1<>0 THEN A3=ATN(A2/A1) ELSE A3=SGN(A2)*PI/2
1350 IF SGN(A1)<0 THEN A3=A3+PI
1360 IF SGN(A1)>0 AND SGN(A2)<0 THEN A3=A3+2*PI
1380 D(IC)=A3*DPR:A1(IC)=D(IC)
1390 RETURN
1500 '
1505 '  CONVERT RTD READINGS TO DEG. C.
1510 '
1545   T=(A1(IC))/RC(1)/G(C(IC))
1550   A1(IC)=-245.665+T*(235.476+10.189*T)
1565 RETURN
1600 '
1601 '       PULSE BOWEN RATIO DEVICE
1602 '
1605 ' CHANNEL:   1   2   3   4   5   6  ALL OFF
1607 '
1608 GOSUB 9300
1610 OUT PN,67: X=INP(PN):'1&2ON
1615 FOR I=1 TO 3000:NEXT
1620 OUT PN,64 : X=INP(PN):'ALLOFF
1625 RETURN
1700 '
1701 '             ONLINE CALCULATIONS
1705 ' SUB5,6 = PRESENT VAL., SUB7,8 = PAST VAL., SUB9,0 =
     RUNNING AVE.
1706 'SUB5,7,9 (-CH9,11 ON RIGHT SIDE) ARE UP WHEN HOME
     SIGNAL IS +
1707 '   *** SAVE PRESENT VALUES ***
1708 '
1710 G7(K9)=G5:Q7(K9)=Q5
1712 TAV7(K9)=TAV5:WAV7(K9)=WAV5
1715 T7(K9)=T5:T8(K9)=T6:W7(K9)=W5:W8(K9)=W6
1720 '
1725 Q5=A2(2):G5=A2(1)
1727 S4=S7:S7=S5:S5=A2(13)
1730 TAV5=(A2(J)+A2(J+2))/2:WAV5=(A2(J+1)+A2(J+3))/2
1735 P1=SGN(A(HOME)):IF P1=1 THEN IALT=0 ELSE IALT=2
1740 T5=A2(J+IALT):T6=A2(J-IALT+2):W5=A2(J+IALT+1):W6=A2(J-
     IALT+3)
1744 '
1745 '   *** FIND RUNNING AVERAGES ***
1746 '
1750 Q=(Q7(K9)+Q5)/2:G=(G7(K9)+G5)/2
1755 T=(TAV5+TAV7(K9))/2:TW=(WAV5+WAV7(K9))/2
```

```
1760
     T9=(T5+T7(K9))/2:T0=(T6+T8(K9))/2:W9=(W5+W7(K9))/2:W0=(
     W6+W8(K9))/2
1784 '
1785 '  *** MISCELLANEOUS PARAMETERS ***
1786 '
1790 TT=T:W=TW:GOSUB 2015:EA=EFN
1792 TT=T0:W=W0:GOSUB 2015:E0=EFN
1793 CP=(239.9+440.9*.622*EA/(P-EA))/.2388
1795 XL=2501300!-2366*TW:GOSUB 2030:S0=S
1800 G1=P*CP/(.622*XL):R0=3.4838*(P-.378*EA)/(T+273.16)
1805 S1=9.810001/CP:TT=TW:GOSUB 2030
1810 S2=9.810001*(1/CP+.0034857*EA/(273.16+T)/G1)/(1+S/G1)
1815 S3=9.810001*.0034857*EA/(273.16+T)
1819 '
1820 '  *** GRADIENTS ***
1821 '
1825 TT=T9:W=W9:GOSUB 2015:E9=EFN
1830 DT=T9-T0+S1*DELZ(K9)
1835 DE=E9-E0+S3*DELZ(K9)
1859 '
1860 '  *** BOWEN RATIO USING T, E ***
1861 '
1862 GF1=-CH*1000000!*DZ*(S5-S4)/(2*N1*60)
1865 B=G1*DT/DE
1870 H=(-Q-G-GF1)/(1+1/B):E=H/B
1872 '
1873 '  *** RADIATION BALANCE ***
1874 '
1877 KUP=-A2(4):KDN=A2(3)
1880 IF KDN<=0 THEN A=0 ELSE A=-KUP/KDN ' ALBEDO
1885 QUP=-SIGMA*(A2(14)+273.16)^4-A2(16)
1890 QDN=SIGMA*(A2(14)+273.16)^4+A2(6)
1895 LUP=QUP-KUP:LDN=QDN-KDN:QN=QDN+QUP
1910 RETURN
1950 '
2000 '  * * *  MISCELLANEOUS FUNCTIONS  * * *
2005 '
2015
     ESAT=(E(1)+W*(E(2)+W*(E(3)+W*(E(4)+W*(E(5)+W*(E(6)+W*(E
     (7))))))))/10
2020 EFN=ESAT-.00066*(1+.00115*W)*P*(TT-W)
2025 RETURN
2030
     S=(S(1)+TT*(S(2)+TT*(S(3)+TT*(S(4)+TT*(S(5)+TT*(S(6)+TT
     *(S(7))))))))/10
2035 RETURN
2050 '
2100 '  * * *  MISCELLANEOUS CONSTANTS  * * *
2105 '
2115 E(1)=6.1078
2116 E(2)=.44365185#
2117 E(3)=.014289458#
2118 E(4)=.00026506485#
```

```
2120 E(5)=3.031240400000003D-06
2121 E(6)=.000000020340809#
2125 E(7)=6.136820900000027D-11
2126 '
2130 S(1)=.44381
2131 S(2)=.028570026#
2132 S(3)=7.93805E-04
2133 S(4)=.000012152151#
2135 S(5)=.00000010365614#
2136 S(6)=3.532421800000003D-10
2140 S(7)=-7.090244800000049D-13
2141 '
2145 B1=25.661297#
2146 B2=-.619548690000003#
2147 B3=.022181644#
2148 B4=-3.5509E-04
2150 RETURN
2200 '
2205 '  SAVE RAW DATA ON DISK
2210 '
2220 IS=J9-N4+1:IE=J9:TPE=0:IF IS<1 THEN IS=1
2230 CLS:FN$="1:D"+RIGHT$(DATE$(DATE$,2)
2240 'IFVAL(LEFT$(TIME$,2))=<12THENZN$="0:D"+RIGHT$(DATE$,2)
2245 PRINT"FILENAME="FN$
2250 GOSUB 9300
2255 OUTPN, 76:'DRIVE ON
2260 FOR J=0 TO 500:NEXT
2270 PRINT"WRITING TO DISK..."
2275 FOR J1=IS TO IE:FOR I=1 TO (M-1)
2280 PRINT#1,;DS%(J1,I);:NEXT:PRINT#1,DS%(J1,M):NEXT
2285 PRINT TIME$;" REC= ";J1;
2290 GOSUB 9300
2294 FOR I=1 TO 4
2295 OC(I)=0:NEXT:OUTPN,64:PRINT"DRIVE OFF"
2299 RETURN
2500 '
2505 '  PRINT SUMMARY
2510 '
2515 LPRINT TIME$;" ";DATE$
2520 MCOL=4
2525 FOR I=1 TO MCOL
2530   LPRINT "CHAN  RAW      ENG ";
2535 NEXT:LPRINT
2540 FOR I=1 TO M7 STEP MCOL
2545   FOR K=I TO MCOL+I-1
2550     IF K>M7 THEN 2575
2565     LPRINT USING "### #####
     #####.###";C(K);DS%(J9,K);INT(1000*A2(K))/1000;
2570   NEXT:LPRINT
2575 NEXT:LPRINT
2580 '
2600 '     DISPLAY ENERGY, RAD BALANCE
2601 '
2605 LPRINT "     H       E       B       Q        G";
```

```
2610 LPRINT "     KDN      KUP     LUP      LDN      THR"
2615 LPRINT USING F1$;H;E;B;Q;G+GF1;
2620 LPRINT USING F2$;KDN;KUP;LUP;LDN;THR
2625 LPRINT "     TT      TWT      E       DT      DE";
2630 LPRINT "     U       DIR"
2635 LPRINT USING F3$;T9;W9;E9;DT;DE;
2640 LPRINT USING F1$;A2(17);A1(8)
2645 FOR I=1 TO 10:LPRINT "- - - ";:NEXT:LPRINT:RETURN
2650 LPRINT "     CP      L       S     GAMMA    RHO HOME"
2655 LPRINT USING F4$;CP;XL/1000000!;S0*1000;G1*1000;R0;P1
2660 RETURN
2690 '
2695 GRADIENT DISPLAY
2710 CLS:GOSUB 120:LOCATE 0,1
2715 PRINT "ITEM   CURRENT   PAST   AVERAGE   INSTAN."
2720 D=DELX(K9):Z1=S1:Z2=S2:Z3=S3
2722 J=9:IF SGN(A(HOME))=1 THEN I=0 ELSE I=2
2725 IF DSP$="H" THEN Z1=0:Z2=0:Z3=0
2730 PRINT "delT ";:PRINT USING F3$;T5-T6+Z1*D:T7(K9)-
     T8(K9)+Z1*D;T9-T0+Z1*D;A1(J+I)-A1(J-I+2)+Z1*D
2735 PRINT "delTw ";:PRINT USING F3$;W5-W6+Z1*D:W7(K9)-
     W8(K9)+Z1*D;W9-W0+Z1*D;A1(J+I+1)-A1(J-I+3)+Z1*D
2745 PRINT " Tbot";:PRINT USING F3$;T6:T8(K9);T0;A1(J-I+2)
2750 PRINT " Ttop";:PRINT USING F3$;T5:T7(K9);T9;A1(J+I)
2760 PRINT " Twbot";:PRINT USING F3$;W6:W8(K9);W0;A1(J-I+3)
2765 PRINT " Twtop";:PRINT USING F3$;W5:W7(K9);W9;A1(J+I+1);
2790 RETURN
9000 '
9005 ' * INITIALIZE CONTROL PARAMS *
9010 '
9030   DPR=57.2958  '  DEGREES/RADIAN
9055   SIGMA=5.6697E-08' BOLTZMAN CONST
9070   PN=1016        '  SERIAL PORT DATA
9080   PI=3.14159:C=0
9106   P=101.3-.01055*ELEV ' ASSUME STD ATMOSPHERE
9110 OPEN "INDAT8" FOR INPUT AS #2
9112 INPUT #2,X$    ' SKIP LABEL
9115 INPUT #2,M,N1,N2,N3,N4,N5,N8,G0,M7
9120 N4=N4/N1   '  SET N4=# OF RECORDS/DISK UPDATE
9123 M9=20
9125 DIM D(M9),A(M9),A1(M9),A2(M9),LA$(M9)
9130 DIM C(M9),C1(M9),G(M9),B(M9),G2(M9)
9132 DIM B2(M9),N(M9),B1(M9)
9135 INPUT #2,X$   ' SKIP LABEL
9136 INPUT #2,XLG,HG,HOME,REF,O1,O2,RC(1),NCRTD
9137 INPUT #2,X$   ' SKIP LABEL
9138 INPUT #2,DELZ(1),ELEV,CH,DZ,REF,SYSID
9139 INPUT #2,X$   ' SKIP LABEL
9140 FOR K=1 TO M7
9145  INPUT #2,C(K),C1(K),G(K),B(K),N(K),LA$(K)
9150  IF C1(K)=0 THEN G2(K)=1/XLG ELSE G2(K)=1/HG
9155  IF C1(K)=1 THEN B1(K)=O1
9160  IF C1(K)=3 THEN B1(K)=O2
9165  C1(K)=C1(K)*16+C(K)-1
```

```
9168  IF N(K)=2 THEN NRTD=NRTD+1
9170  IF N(K)=3 THEN NWD =K
9175  IF N(K)=5 THEN NDIG=NDIG+1
9180 NEXT
9193 CLOSE#2
9195 NANLG=M7-NDIG
9235 F1$="#####.# #####.# ###.### #####.# #####.#"
9240 F2$="#####.# #####.# #####.# #####.# #####.#"
9245 F3$="###.### ###.### ###.### ##.#### ##.####"
9250 F4$="####.# ##.### ###.## ###.## ###.## ##.#"
9260 ' CALC DATA BUFFER SIZE
9265 N3=(FRE(0)-1600)/(2*(M+1))
9270 DIM DS%(N3,M)
9275 LOCATE 0,7:PRINT " BUFFER WILL HOLD ";N3*N1/60;" HOURS"
9300 CLOSE:OPEN "COM:8N82NN" FOR INPUT AS #1:CLOSE #1
9320 OUT144,128:'SELECTFDD
9340 OUT216,29:OUT188,16:OUT189,64:'SET BAUD ETC
9340   OUT PN,64    '  ALL DIG. O/P OFF
9500 RETURN
12000 ON ERROR GOTO 0
12002 IF INKEY$=CHR$(27) THEN E2=1
12005 PRINT "ERROR ";ERR;" IN STATEMENT ";ERL
12020 RESUME 1015
```

9.2 ADCTST.BAS, A Test program for the ADC-1 using the NEC computer.

```
10 ' ADCTST:  test for ADC-1    6/7/84
16 ' use control break to stop then type close 2 to save
     data to file
20 '
25  CLS: CN=16: POKE -3188,201
30  GOTO 9300
40  DIM C(16),M(16),N(16),A(16),OFST(16),Q(16),S(16)
105   X=INP(PN)                    :' clear input port of old
     bytes
107 OS=0:N0=1:N1=10:N3=1:C(1)=1:GOTO 170
108 PRINT "0=LOW GAIN"
109 PRINT "16=HIGH GAIN, OFFSET 1"
110 PRINT "32=HIGH GAIN, OFFSET NONE"
111 PRINT "48=HIGH GAIN, OFFSET 2"
115 INPUT "GAIN/OFFSET";OS
120 PRINT "A/D STABILITY AND CALIBRATION TEST"
130 INPUT "NO. OF CHANNELS TO TEST ";N0
140 INPUT "NO. OF SAMPLES TO AVERAGE ";N1
145 INPUT "NO. OF SCANS/SAMPLE ";N3
150 PRINT "SPECIFIY EACH CHANNEL TO TEST "
160 FOR K=1 TO N0:INPUT "?";C(K):NEXT
165 IF C(1)=0 THEN FOR I=1 TO 16:C(I)=I:NEXT
170 Y1=-9.999999E+37:Y2=9.999999E+37
172 INPUT "ENTER D FOR DISK STORAGE OF AVERAGE";D$
173 IF D$="D" THEN GOTO 175 ELSE GOTO 180
175 OPEN "ADCDATA.TXT" FOR APPEND AS 2
176 FOR K=1 TO N0: PRINT #2, USING
     "##########";C(K),C(K),:NEXT
177 PRINT #2,""
180 PRINT
185 N2=10
190 FOR L=1 TO N0: M(L)=-10000:N(L)=10000:NEXT
200 FOR L=1 TO N1
225   GOSUB 800
228   FOR K=1 TO N0
229     IF L=1 THEN OFST(K)=A(K)
230     S(K)=S(K)+A(K)-OFST(K):Q(K)=Q(K)+(A(K)-OFST(K))^2
240     IF A(K)>M(K) THEN M(K)=A(K)
245     IF A(K)<N(K) THEN N(K)=A(K)
250   NEXT
260 NEXT
270 FOR L=1 TO N0
280   Q(L)=SQR(ABS((Q(L)-S(L)^2/N1)/(N1-1)))
290   S(L)=S(L)/N1+OFST(L)
300 NEXT
305 PRINT "CH NO.     AVE     STD DEV    MAX    MIN"
310 FOR L=1 TO N0
320   PRINT USING "###";C(L),
330   PRINT USING "#######.## #######.##";S(L),Q(L),
335   PRINT USING "####### #######";M(L),N(L),
336   PRINT " ",DATE$,TIME$
```

```
342 IF D$<>"D" THEN GOTO 350
344   PRINT #2, USING "#######.##";S(L),Q(L),
345  IF L=NO THEN PRINT #2, " ", DATE$,TIME$
349   Q(L)=0:S(L)=0
350 NEXT
355 PRINT
360 GOTO 190
800 '
801 '    ***  SAMPLE A/D (ADC-1); CONVERT TO DECIMAL  ***
802 '
805 FOR K2=1 TO NO
810  X$=INKEY$:IF X$<>""THEN C1=ASC(X$)
811  IF X$<>"" THEN IF C1>57 THEN C1=C1-7
815  IF C1>48 THEN C(1)=C1-48
816  CN=C(K2)+OS-1
818  FOR I1=1 TO N3
820   OUT PN, CN                               :' select channel;
     start A/D
826   Y=INP(PN)                                :' garbage character
827   FOR K=1 TO 200:NEXT
830   OUT PN,129+32                            :' get ADC-1 high
     byte/status
840   HBYTE=INP(PN)                            :' save high byte
     from A/D
845   IF(HBYTE AND 128) <> 0 THEN 830          :' check status for
     A/D finished
850   OUT PN,129+16                            :' get ADC-1 low
     byte
860   LBYTE=INP(PN)                            :' save LOW byte
     from A/D
865   HMASK=HBYTE AND 15                       :' mask 4 high order
     bits from A/D
870   Y=LBYTE+256*HMASK                        :' combine all 12
     bits from A/D
875   IF (HBYTE AND 16)=0 THEN Y=-Y            :' fix sign if
     negative  flag set
877   IF I1=N3 THEN 880 ELSE 883
880   A(K2)=Y:PRINT USING "#####";Y;
883  NEXT
885 NEXT:PRINT:' HBYTE;HMASK;LBYTE
890 RETURN
1000 C1=VAL(INKEY$)
1010 IF C1<> OC1 THEN CN=C1
1015 OC1=C1
1020 PRINT CN:GOTO 1000
1050 GOTO 1000
9300 CLOSE:OPEN "COM:8N82NN" FOR INPUT AS #1:CLOSE #1
9320 OUT144,128:'SELECTFDD
9340 OUT216,29:OUT188,16:OUT189,64:'SET BAUD ETC
9340   OUT PN,64     '  ALL DIG. O/P OFF
9500 RETURN
```

9.3 SAMPR1.BAS, a program for the AT computer which converts the raw data from the NEC computer into engineering units and calculates the energy and radiation balances.

```
3     'SAMPR1.BAS
4     'This program was developed for systems 1,7,8 and 9.
      June 6, 1988
5     'Check soil moisture file in line 7010.
20    ' Changed as combined
      05/23/88
45    'ICFLG = 0 -> include IS point running mean of G in top
      10 cm
50    '        1 -> exclude G calculation in top 10 cm
55    'IS    = no. of points in soil heat storage running
      mean
60    'FS$   = output file name extension (.MF or R)
65    'FT$   = not used
70    S4=0:S5=0:S7=0
100   ' 3981 for thermal conductivity and 3892 for correct
      soil heat flow.
120   '                                       Last modified
      5/7/86
140   DEFINT I-N,I,J,L-N: M=19 : NS=20:NST=50:NOUT=31
150   DIM T(58),IFLGO(30),IFLGO7(30)
155   DIM
      N(25),D(25),F(17),A$(56),L(56),T$(13),C(51,4),B$(50)
160   DIM A2(21),CH(21),C1(21),G(21),B(21),G2(21)
165   DIM NT(21),B1(21),FL$(120),N$(9)
170   DIM
      DELZ(2),Q7(2),G7(2),TAV7(2),WAV7(2),T7(2),T8(2),W7(2),W
      8(2)
175   DIM RC(2),E(9),S(7),GP(10),RCC(250),RC2(100)
180   RCC=0:'record counter for loop and the first three
      records
185   GOSUB 6100                              ' set
      constants
190   GOSUB 9000:F$=""                        ' Microstat
      init
200   '
205   ' MAIN PROGRAM
210   '
230   M3=0:M2=0:M1=0:S4=0:S5=0:S7=0
240   '
245   ' read input file name
250   '
255   ICOUNT = ICOUNT + 1 : N$=DXI$+FL$(ICOUNT) : N1$=N$+"R"
256   N9$=N$+".DAT"
265   Q5=4
270   GOSUB 2400                              ' set system
      specific info
310   '
315   L1=M :M1=L1          '  NOUT
320   '
```

```
325  C=1 : D=1000
330  N3M=D-C+1
335  '
340  N3$=DXO$+FL$(ICOUNT):Z$=N3$+FS$
350  '
360  FOR L=1 TO L1
370    L(L)=L
380  NEXT
390  GOSUB 6300 '                        read data system
     parameters
395  GOSUB 7010 '                         read soil moisture
400  PRINT F$:PRINT"FILE: " N3$ " IS NOW BEING
     OUTPUT...":J1=0
402  Z$=N3$+".TXT"
404  OPEN Z$ FOR APPEND AS #2
406     FOR L=1 TO (NS+29)
408      PRINT #2, A$(L);
410     NEXT:PRINT #2, A$(NS+30)
412  CLOSE #2
420  '   open input and output files
430  '
440  OPEN "I",#1,N9$   '   OPEN "R",#1,N1$,Q5
450  '                       FIELD #1,Q5 AS T$
460  OPEN Z$ FOR APPEND AS #2
480  '
490  '   main computation loop
500  '
510  FOR J=C TO D
520  '
530  '   read data into T()
540  '
550     FOR K=1 TO L1
560       INPUT #1,T(K) : IF EOF(1) THEN 680
570     NEXT
572  RCC=RCC+1
580     GOSUB 800
590     J1=J1+1:PRINT CHR$(13) J1 INT(T(M-1)/10) T(M) "
     ";
600 '
610 '   write out full T() array
620 '
630     FOR L=1 TO (NS+29)
640      PRINT #2, T(L);
660     NEXT:PRINT #2 ,T(NS+30)
670   NEXT:PRINT F$
680   PRINT "END OF FILE OUTPUT":N$=N1$
690   CLOSE #1:CLOSE #2:PRINT
700  RCC=0
760 IF ICOUNT<IFILES GOTO 200
775 CHAIN "SAMPR2":END
780 '
790 ' MAIN SAMPLING LOOP
800 '
810 FOR I=1 TO M1
```

```
820  IF NT(I)=3 OR I>M1-2 THEN A2(I)=T(I):GOTO 850 'No
     action Time or Udir
830  IF NT(I)=3 AND T(M)<VDATE AND INT(T(M-1)/10)<VTIME THEN
     A2(I)=T(I)+VANE:GOTO 850
840   A2(I)=T(I)*G2(I)+B1(I)  ' A/D UNITS TO MV
850 NEXT
860 FOR IC=1 TO M7
870   ON NT(IC) GOSUB 2400,2340,2420,2400,2400
880 NEXT
890 '
900 TIME =
     INT(A2(18)/10):T(18)=TIME:T(19)=A2(19):T(20)=A2(18)
930 FOR I=1 TO L1 : T(I)=A2(I)  : NEXT
940 TK=.64+1.63*CSOIL-(.64-.135)*EXP(-((17*CSOIL)^2)):'TK is
     thermal conductivit
950 PRINT "TK= ",TK
960 T(1)=T(1)*(1-1.92*.138*(1-(TK/.48)))/(1-1.92*.138*(1-
     (.94/.48)))
970 'Above is heat flow correction-see Fritschen and Gay
980 GOSUB 3600
1000 RETURN
2340 '
2350 '  CONVERT RTD READINGS TO DEG. C.
2360 '
2370   T=(A2(IC))/RC(1)/G(CH(IC))
2380   A2(IC)=-245.665+T*(235.476+10.189*T)
2390   RETURN
2400  '
2405  ' MV TO ENG. UNITS, LINEAR
2410  '
2415  A2(IC)=A2(IC)*G(IC)+B(IC)
2420  RETURN
2430 '
2435 ' read system specific data
2440 '
3600 '
3605 ' MAIN PROCESSING LOOP
3610 A2(HOME)=A2(7)
3785 P1=SGN(A2(HOME)): '             Home signal processing
3890 '
3895 J8=NCRTD : I9 = 1 : GOSUB 4000  '         Energy and
     radiation balance
3898 '
3900 T(NS) =QSTAR    : T(NS+1) =H       : T(NS+2)= E       :
     T(NS+3) =GP
3920 T(NS+4) =LDN    : T(NS+5) =LUP     : T(NS+6)=T9       :
     T(NS+7)=W9
3930 T(NS+8)=T0      : T(NS+9)=W0       : T(NS+10)=A2(13)  :
     T(NS+11)=E9
3940 T(NS+12)=E0     : T(NS+13)=DT      : T(NS+14)=DE      :
     T(NS+15)=QDN
3950 T(NS+16)=QUP    : T(NS+17)=RHB     : T(NS+18)=GS      :
     T(NS+19)=BR
```

```
3970 T(NS+20)=HBR     : T(NS+21)=EBR     : T(NS+22)=HALT    :
     T(NS+23)=EALT
3972 T(NS+24)=CV#     : T(NS+25)=RB      : T(NS+26)=RAIN    :
     T(NS+27)=Q9-QN
3974 T(NS+28)=KDN     : T(NS+29)=KUP     : T(NS+30)=A2(5)
3980 RETURN
4000 '
4005 '               Bowen ratio energy balance - 2 point
     running mean
4010 ' SUB5,6 = PRESENT VAL., SUB7,8 = PAST VAL., SUB9,0 =
     RUNNING AVE.
4015 RAIN=A2(17)
4020 Q9=A2(2):G5=A2(1)
4025 S4=S7:S7=S5:S5=A2(13) ' S7=Tsoil at TIME-6 mins; S4 at
     TIME-12 mins
4030 TAV5=(A2(J8)+A2(J8+2))/2:WAV5=(A2(J8+1)+A2(J8+3))/2
4035 IF P1=1 THEN IALT=0 ELSE IALT=2
4040 T5=A2(J8+IALT):T6=A2(J8-
     IALT+2):W5=A2(J8+IALT+1):W6=A2(J8-IALT+3)
4051 '
4052 '  *** FIND RUNNING AVERAGES ***
4053 '
4054 QSTAR=(Q7+Q9)/2:GP=(G7+G5)/2:QN9=(QN7+QN5)/2
4055 T=(TAV5+TAV7)/2:TW=(WAV5+WAV7)/2
4059 T9=(T5+T7)/2:T0=(T6+T8)/2:W9=(W5+W7)/2:W0=(W6+W8)/2
4060 IF RCC = 1 THEN GOSUB 5670:'STARTUP AVERAGES
4064 '
4065 '  *** SAVE PRESENT VALUES ***
4066 '
4070 G7=G5:Q7=Q9:QN7=QN5:'THR NET
4075 TAV7=TAV5:WAV7=WAV5
4080 T7=T5:T8=T6:W7=W5:W8=W6
4084 '
4085 '  *** MISCELLANEOUS PARAMETERS ***
4086 '
4090 TT=T:W1=TW:GOSUB 6015:EA=EFN
4092 CP=(239.9+440.9*.622*EA/(PRES-EA))/.2388
4095 XL=2501300!-2366*TW:GOSUB 6030:S0=S
4100 G4=PRES*CP/(.622*XL):R0=3.4838*(PRES-
     .378*EA)/(T+273.16)
4105 S1=9.810001/CP:TT=TW:GOSUB 6030
4110 S2=9.810001*(1/CP+.0034857*EA/(273.16+T)/G4)/(1+S/G4)
4115 S3=9.810001*.0034857*EA/(273.16+T)
4119 '
4120 '  *** GRADIENTS ***
4121 'IF QSTAR >0 THEN T0=T0-.0006*QSTAR
4122 TT=T9:W1=W9:GOSUB 6015:E9=EFN:EA=E9
4123 CP=(239.9+440.9*.622*EA/(PRES-EA))/.2388:XL=2501300!-
     2366*W1
4124 GOSUB 6019: E9=EFT:W1=T9:GOSUB 6015:RHT=100*E9/ESAT
4126 TT=T0:W1=W0:GOSUB 6015:E0=EFN:EA=E0
4127 CP=(239.9+440.9*.622*EA/(PRES-EA))/.2388:XL=2501300!-
     2366*W1
4128 GOSUB 6019: E0=EFT:W1=T0:GOSUB 6015:RHB=100*E0/ESAT
```

```
4130 DT=T9-T0+S1*DELZ(1)
4135 DE=E9-E0+S3*DELZ(1)
4159 '
4160 '  *** BOWEN RATIO USING T, E ***
4162 'Convert %H20(G/G) to volumetric and calc heat
     capacity.
4164 GS = -CSOI*DZ*(S5-S4)/(2*N1*60):IF RCC < 4 THEN
     GS=G5:'heat storage.
4166 BR = G4*DT/DE:QAV = QSTAR+GP+GS
4168 H = (-QAV)/(1+1/BR):E = H/BR:HBR=H:EBR=E
4170 GOSUB 5005
4171 IF SGN (E) <> SGN (DE) THEN H=HALT
4172 IF (-.75 > BR) AND (BR > -1.25) THEN H=HALT
4173 E = -(QAV+H)
4174 '  *** RADIATION BALANCE ***
4175 '
4177 KUP=-A2(4):KDN=A2(3)
4180 IF KDN<=0 THEN A=0 ELSE A=-KUP/KDN ' ALBEDO
4200 '
4205 ' Diffuse correction, per LI-COR 2010S shadow band
     manual
4210 ' NOTE: Eppley and not LI-COR used for total solar
     radiation
4215 '
4220 IF KDN<=0 THEN 4235 ELSE A2(5)=A2(5)*1.13 '
     Table I
4225 A2(5)=A2(5)/(1.17-(1/(1.2+11.8*(A2(5)/KDN))))'
     Spectral correction
4235 '
4245 IF KDN<0 THEN KDN=0
4250 IF KUP>0 THEN KUP=0
4255 IF A2(5)<0 THEN A2(5)=0
4256 IF KDN <= 0 THEN A2(5)=0
4257 QUP=-(SIGMA*(A2(14)+273.16)^4+A2(16))
4260 QDN=SIGMA*(A2(14)+273.16)^4+A2(6)
4261 IF QDN > 3000 THEN QDN=3000:IF QUP < -3000 THEN QUP=-
     3000
4265 LUP=QUP-KUP:LDN=QDN-KDN:QN=QDN+QUP:QN5=QN
4280 RETURN
5005 'ALTERNATE CALCULATIONS OF H AND E
5006 WS=A2(15)
5008 CV#=-(QAV)/((WS*CP*DT)+(WS*XL*.622*DE/PRES))
5501 RB=9.810001*DT*3.24/((TT+273)*WS^2):'3.24=(Z-ZO)^2
5508 IF RB > .006 THEN GOTO 5515
5510 CVA#=-2.567*RB + .0246:GOTO 5540
5515 CVA#=-.0123*RB + .0246
5540 HALT=CVA#*WS*CP*DT
5550 EALT=CVA#*XL*WS*.622*DE/PRES
5634 RETURN
5670 'STARTUP AVERAGES
5671 QSTAR=Q9:GP=G5:QN9=QN5:T=TAV5:TW=WAV5
5672 T9=T5:T0=T6:W9=W5:W0=W6:RETURN
6000 '
6005 '  * * *  MISCELLANEOUS FUNCTIONS  * * *
```

```
6010 '
6015
     ESAT=(E(1)+W1*(E(2)+W1*(E(3)+W1*(E(4)+W1*(E(5)+W1*(E(6)
     +W1*(E(7))))))))/10
6016 EFN=ESAT-.00066*(1+.00115*W1)*PRES*(TT-W1)
6017 RETURN
6019
     ESAT=(E(1)+W1*(E(2)+W1*(E(3)+W1*(E(4)+W1*(E(5)+W1*(E(6)
     +W1*(E(7))))))))/10
6020 EFT=ESAT-(CP/(.622*XL))*PRES*(TT-W1)
6021 RETURN
6030
     S=(S(1)+TT*(S(2)+TT*(S(3)+TT*(S(4)+TT*(S(5)+TT*(S(6)+TT
     *(S(7))))))))/10
6035 RETURN
6050 '
6100 '   * * *  MISCELLANEOUS CONSTANTS   * * *
6105 '
6115 E(1)=6.1078
6116 E(2)=.44365185#
6117 E(3)=.014289458#
6118 E(4)=.00026506485#
6120 E(5)=3.031240400000003D-06
6121 E(6)=.000000020340809#
6125 E(7)=6.136820900000059D-11
6126 '
6130 S(1)=.44381
6131 S(2)=.028570026#
6132 S(3)=7.93805E-04
6133 S(4)=.000012152151#
6135 S(5)=.00000010365614#
6136 S(6)=3.532421800000003D-10
6140 S(7)=-7.090244800000164D-13
6150 RETURN
6200 '
6300 ISYS=VAL(MID$(N1$,4,1))
6305 INFL$="INDAT"+RIGHT$(STR$(ISYS),1)+".88"
6310 OPEN "I", #1,INFL$:NDIG=0:NRTD=0
6312 INPUT #1,X9$    ' SKIP LABEL
6315 INPUT #1,M,N1,N2,N3,N4,N5,N8,G0,M7
6320 N4=N4/N1   '  SET N4=# OF RECORDS/DISK UPDATE
6335 INPUT #1,X9$   ' SKIP LABEL
6336 INPUT #1,LG!,HG,HOME,REF,O1,O2,RC(1),NCRTD
6337 INPUT #1,X9$   ' SKIP LABEL
6338 INPUT #1,DELZ(1),ELEV,CSOIL,DZ,REF,SYSID
6339 INPUT #1,X9$
6340 FOR K8=1 TO M7
6344 PRES=101.3-.01055*ELEV:'ASSUME STAND ATMOSPHERE
6345  INPUT #1,CH(K8),C1(K8),G(K8),B(K8),NT(K8),X9$
6350  IF C1(K8)=0 THEN G2(K8)=1/LG! ELSE G2(K8)=1/HG
6355  IF C1(K8)=1 THEN B1(K8)=O1
6360  IF C1(K8)=3 THEN B1(K8)=O2
6365  C1(K8)=C1(K8)*16+CH(K8)-1
6368  IF NT(K8)=2 THEN NRTD=NRTD+1
```

```
6370  IF NT(K8)=3 THEN NWD =K8
6375  IF NT(K8)=5 THEN NDIG=NDIG+1
6380 NEXT
6395 NANLG=M7-NDIG
6399 CLOSE #1
6400 PRES=101.3-.01055*ELEV ' ASSUME STD ATMOSPHERE, ELEV =
     ELEVATION (M)
6401 RETURN
7010 ' THIS IS A PROGRAM FOR FINDING SOIL MOISTURE FROM THE
     SOIL MOISTURE
7020 ' DATE FILE CALLED "MOIST88" THEN AUTOMATICALLY PUT IT
     INTO THE
7030 ' "INDAT8.DO FILE"
     DATE:5-24-88
7040 OPEN "I", #3, "MOIST88"
7050 DIM SDT$(144),SW(144,6)
7060 FOR I=1 TO 144
7070 INPUT #3, SDT$(I)
7080 FOR J=1 TO 6
7090 INPUT #3, SW(I,J)
7100 NEXT J
7110 NEXT I
7120 CLOSE #3
7130 M$=MID$(N3$,3,8)
7140 SYS$=MID$(M$,2,1)
7150 DA$=MID$(M$,3,6)
7160 FOR I=1 TO 144
7170 IF DA$=SDT$(I) THEN 7200
7180 NEXT
7200 IF SYS$="1" THEN CSOIL=SW(I,1):GOTO 7260
7210 IF SYS$="2" THEN CSOIL=SW(I,2):GOTO 7260
7220 IF SYS$="3" THEN CSOIL=SW(I,3):GOTO 7260
7230 IF SYS$="7" THEN CSOIL=SW(I,4):GOTO 7260
7240 IF SYS$="8" THEN CSOIL=SW(I,5):GOTO 7260
7250 IF SYS$="9" THEN CSOIL=SW(I,6):GOTO 7260
7260 PRINT"FILE NAME=";M$;" SYSTEM=";SYS$;" DATE=";DA$;"
     CSOIL=";CSOIL
7265 CSOI=(.402*2+4.23*CSOIL)*10^6:'CONVERT %H20 TO HEAT
     CAPACITY
7270 RETURN
9000 '
9010 '   *INIT*
9020 '
9120 R$=CHR$(13)+"    "
9300 '
9305 ' * INITIALIZE CONTROL PARAMS *
9310 '
9315  ' NCRTD=9            '  Channel number of 1st RTD
9320  ' N1=6               '  Basic data rate (min)
9330   DPR=57.2958       '  DEGREES/RADIAN
9340   SIGMA=5.6697E-08  '  BOLTZMAN CONST
9350   PI=3.14159
9360  ' DZ=.1              '  depth of Ts avg (m)
9365  ' HOME=7             '  HOME CHANNEL
```

```
9370 OPEN "I",#1,"PDS.FIL"
9380 INPUT #1,PG$:IF PG$<>"SAMPR1"THEN 9380
9517 INPUT #1,ICFLG,IS,IE,DXI$,DXO$,FS$,FT$,MSG$
9520 IFILES=0
9525 IFILES=IFILES+1 : INPUT #1,FL$(IFILES):IF EOF (1) THEN
     9540 ELSE 9530
9530 IF FL$(IFILES)="END" THEN IFILES=IFILES-1:GOTO 9540
9535 PRINT IFILES;FL$(IFILES),:GOTO 9525
9540 CLOSE #1:PRINT IFILES;FL$(IFILES)
9799 '
9800 ' Field (variable) names
9805 '
9820 DATA "G    ","Q    ","Kdn  ","Kup  ","D    ","Qds
     ","HOME ","Udir "
9830 DATA "Tar  ","Twr  ","Tal  ","Twl  ","Tsoil ","Tthr
     ","U    ","Qus  "
9850 DATA "RAIN ","TIME  ","DATE "
9870 FOR I=1 TO NST:READ A$(I):NEXT
9880 DATA "Q    ","H    ","E    ","Gp   "
9890 DATA "Ldn  ","Lup  ","TAtop ","TWtop ","TAbot ","TWbot
     "
9900 DATA "Tsoil ","EAtop ","EAbot ","DT   ","DE   ","Qdn
     ","Qup  "
9910 DATA "RHbot ","Gs    "," BR  ","Hbr  ","Ebr  ","Halt
     ","Ealt "
9920 DATA "CV   ","RB   ","RAIN ","Qerr ","Kdn  ",Kup  ","D
     "
9930 RETURN
9940 '
```