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METEOROLOGICAL DATA ACQUISITION SYSTEM, SEPTEMBER 1, 1970 - DECEMBER 31, 1970

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ABSTRACT

The primary effort in the meteorological portion of IBP for this interim period was to evaluate the potential of the 36-channel data acquisition system. This evaluation was done through continuous operation of the system, analysis of typical data, and establishment of calibration procedures. The data acquisition system collected meteorological information from two contrasting plots separated 1,000 ft apart. Air and soil temperature, radiation, wind speed, wind direction, and humidity parameters were monitored by the recording system. Final plans were approved, and construction is nearing completion for a relatively undisturbed 3-m diameter lysimeter.

I. METEOROLOGICAL DATA ACQUISITION SYSTEM

System Performance

While very large amounts of valuable data were obtained during the year, experimentation with combined analysis of the system suggests possibilities for improvement. The precision was determined to be two to three percent, and serious drift characteristics were associated with current leakage in the amplifiers.

It was determined that the voltage controlled oscillators (VCO's) used for the conversion of analog data to digital data needed redesigning. It was also determined that design changes for amplifiers used in conjunction with low output transducers, such as net and longwave radiometers, were needed.

Difficulties were experienced with the electronic components of the recording system, particularly in the integrated circuit boards used in conjunction with the counter storages and with the amplifier cards used in conjunction with the temperature transducers. These difficulties were finally traced to a defective batch of operational amplifiers furnished by one of the electronic suppliers and to the temperature sensitivity of some of the components. Even though the defective parts were replaced by the suppliers, the difficulty prolonged the time necessary to make the data acquisition system operational.

The VCO's referred to above were redesigned and built with specifications calling for an accuracy of ±0.02% from sensor output to digital placement of data on magnetic tape and a drift of not more than 0.1% in five hours. The VCO's were redesigned to supply an integrated analog output of signals received from various sensors during a one-minute interval. Counters used in connection with the VCO's digitized the integrated one-minute analog outputs suitable for placement on magnetic tape.

Integrated components designed for low level operation were built into amplifiers for low level output transducers to give the necessary amplification for radiation measurements.

System Calibration Procedures

A procedure was developed for calibrating the VCO's. The calibration was accomplished by the following procedures: First, removing the amplifier card from the channel to be calibrated, substituting the extender card into the amplifier, connecting a precision voltage source to the output pin of the amplifier, and connecting the ground terminal of the precision voltage source of the extender card. This procedure was necessary because there was an offset voltage between the amplifier chassis and the VCO chassis due to ground currents in the ground busbars. Second, the precision voltage sources was set to 50 millivolts, and the VCO frequency trim potentiometer on the VCO was adjusted until the digital indicator on the console front panel read 100 ± 2. Third, the precision voltage source was set at 4.500 volts, and the high frequency potentiometer on the VCO was adjusted until the digital indicator on the console front panel read 100 ± 2. Fourth, the precision voltage source was set at 4.500 volts, and the high frequency potentiometer on the VCO was adjusted until the digital indicator on the console front panel read 900 ± 2. Fifth, steps 2 and 3 were repeated until they yielded 100 ± 2, respectively.

In addition, procedures were established for the calibration of the amplifiers on each of the individual transducers. Since the amplifiers were linear devices, the point-slope method of calibration was used. (All non-linearities were accounted for in the computer program for data reduction.) The calibration procedure consists of disconnecting the transducers and connecting a precision voltage source at the input to the amplifier. The voltage source was first set to low end point value for the associated transducer and the low value potentiometer set to give an output voltage of the amplifier of 0.000 volts ± .005 volts. The voltage source was then set to the high end point value and the amplifier slope potentiometer adjusted to give an amplifier output value of 5.000 volts ± .005 volts. These two steps were repeated until the end points remain at 0.000 volts ± .005 volts and 5.000 volts ± .005 volts, respectively. The data for the transducer output voltage required for this calibration procedure was obtained by precision laboratory measurements made on the transducers at the University of Wyoming Electronic Laboratories.

II. CALIBRATION AND MAINTENANCE OF SENSORS

Temperature Sensors

The P-N Junction (electrical diode, IN 3193), which was used for all temperature measurements, was recalibrated to examine the response characteristics of the transducer. The diodes were placed within a plexiglass container which was, in turn, placed within a refrigerated oven capable of producing temperatures between -10°C and +50°C. A voltage reading was taken from each diode at each of seven temperatures (-10, 0, 10, 20, 30, 40, and 50°C) with a precision voltmeter. The data secured was used to determine the coefficient regressing voltage and temperature. In effect, this coefficient was the slope of the temperature response curve of the diode. The value of this was utilized to determine what adjustments should be made on amplifiers and oscillators within the recording system.

Radiation Sensors

The radiation sensors were calibrated in the field on clear days when the solar angle was the greatest. The Epply pyranometer, which is used for routine daily solar energy measurements, was compared against a temperature-compensated pyranometer to verify its calibration constant to a precision of .01 langleys per minute. The KIPP solarimeters (a transducer used for measurement of reflected short wave radiation) were recalibrated by inverting them to the upright position and comparing the output at the solarimeter to that of the previously mentioned temperature-compensated pyranometer.

A shading technique was required for calibration of the net radiometers. The net radiometers and the temperature-compensated pyranometer were shaded simultaneously until both sensors had reached equilibrium. At this time, output readings were taken from both transducers. The shades were then removed, and the sensors were allowed to come to equilibrium. A second set of output readings was again obtained. The amount of energy shaded from each transducer was assumed to be equal. The new calibration constant was calculated from the expression

$$\frac{\nabla E_{NET}}{K_{NET}} = \frac{\nabla E_E}{K_E}$$

where:

∇E_{NET} = difference due to shading in millivolt output readings from net radiometer,

K_{NET} = calculated net radiometer calibration constant in millivolts per langley per minute,

ΔE_E = difference due to shading in millivolt output readings from the pyranometer,

K_E = calibration constant of pyranometer in millivolts per langley per minute.

An infrared thermometer with 1°F precision was used to check the calibration constant of the long wave radiation sensors. This was accomplished by obtaining simultaneous readings from the infrared thermometer and the long wave transducer.

Humidity and Wind Sensors

Calibration procedures were not conducted for the humidity or wind sensors because the calibration furnished with the humidity sensors was noted to be valid for an indefinite period of time due to the principle of operation used. The wind speed transducers were compared against each other at a common height. The results showed that they were in agreement within the accuracy limits of the transducer itself.

A routine maintenance check was performed three times a week. During each check, all radiation sensors were visited and examined for deposit of foreign matter. The humidity sensors were balanced and cleaned. All channels of the recording system were examined for analog and digital agreement, as well as for proper time and coding.

III. DATA ANALYSIS

The following analysis of data was prepared to illustrate and explain the type of data being obtained at the Pawnee Site. The entire discussion was based on data obtained on May 19, 1970 and September 19, 1970. The conclusions made are only indications of what long term studies might yield.

Radiation

The percent radiation which is reflected from the grassland canopy is commonly termed albedo. This average daily percentage was found to differ between the upland and bottomland treatments by up to 3% (Table 1). This increase reflectance from the bottomland is apparently due to a greater amount of vegetative cover present on the bottomland.

Net radiation (the difference between total incoming and total outgoing radiation) from the upland (Fig. 1), was found to be approximately .1 langley per minute greater than that from the bottomland during mid-day. This difference is partly attributable to the lesser reflectance from the upland plus differences in surface temperatures, soil diffusivities, and suspected differences in evaporation rates from the two situations.

Wind Speed

The wind velocities shown in Fig. 2 for the two areas of interest were very similar in magnitude and direction. No significant difference was detected between the two sites with the present sensing equipment. Differences in wind speeds from 50 cm/second to 75 cm/second were noted between the 50 cm height and 200 cm height.

Air Temperature

Differences in air temperatures were noted between the upland and bottomland (See Fig. 3). The air temperature, 200 cm over the surface of the upland, tends to be 3°F to 5°F warmer than over the bottomland. This was probably due to the fact that the bottomland had a greater area of exposed bare soil that could result in a greater amount of sensible heat transfer to the atmosphere. The temperature gradient, as measured at the 50 cm and

Table 1. Albedo (percent) of Pawnee Site for total solar radiation with diffuse reflection for September 19, 1970.

Time	Albedo	
Military	Upland	Bottomland
0600	0.0	00.
0700	5.	10.
0800	9.	13.
0900	12.	14.
1000	12.	14.
1100	12.	14.
1200	12.	15.
1300	12.	15.
1400	11.	15.
1500	8.	15.
1600	2.	09.
1700	0.	00.
Daily Average	10.7	13.8

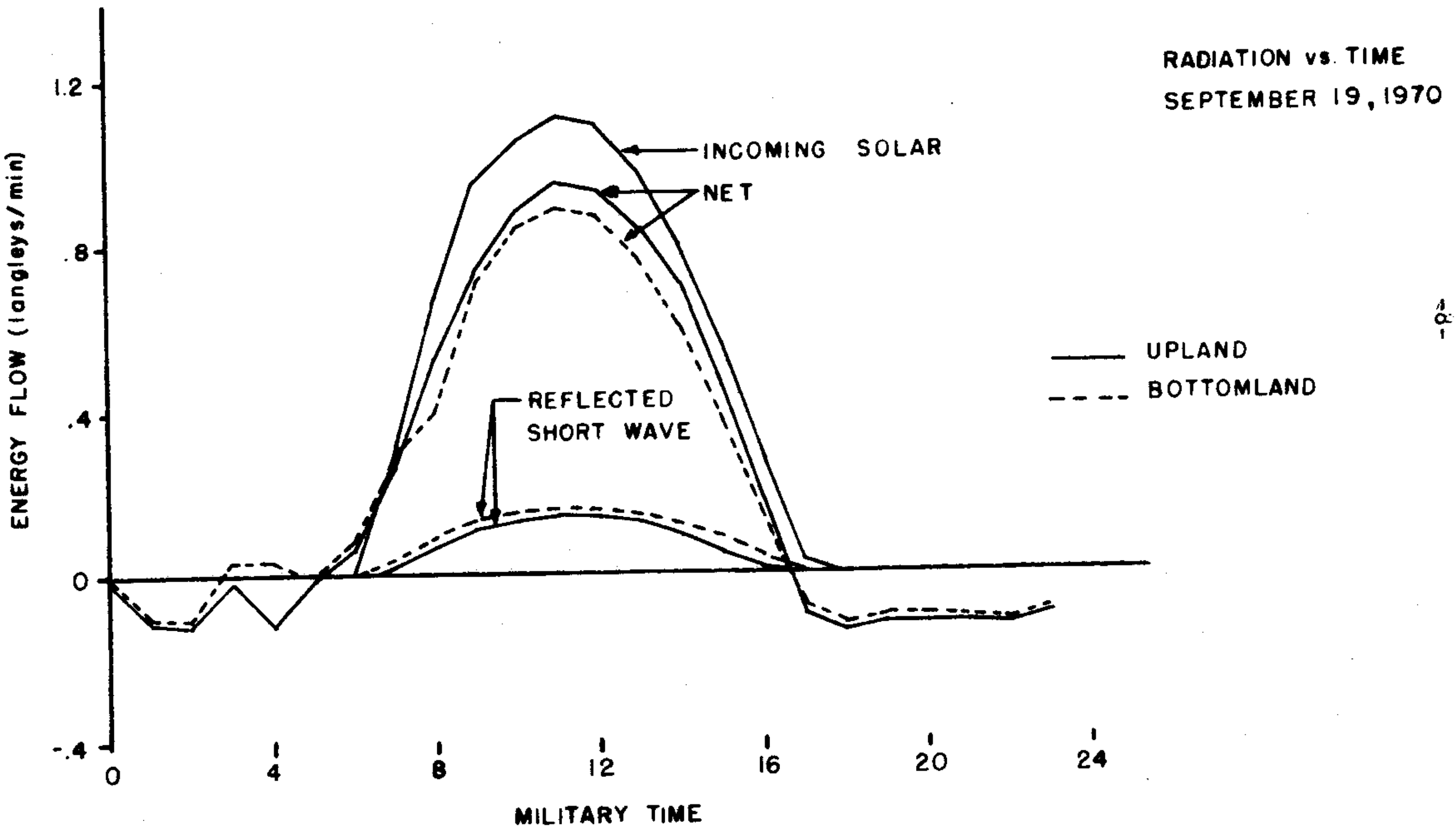

Fig. 1. Radiation parameters for September 19, 1970.

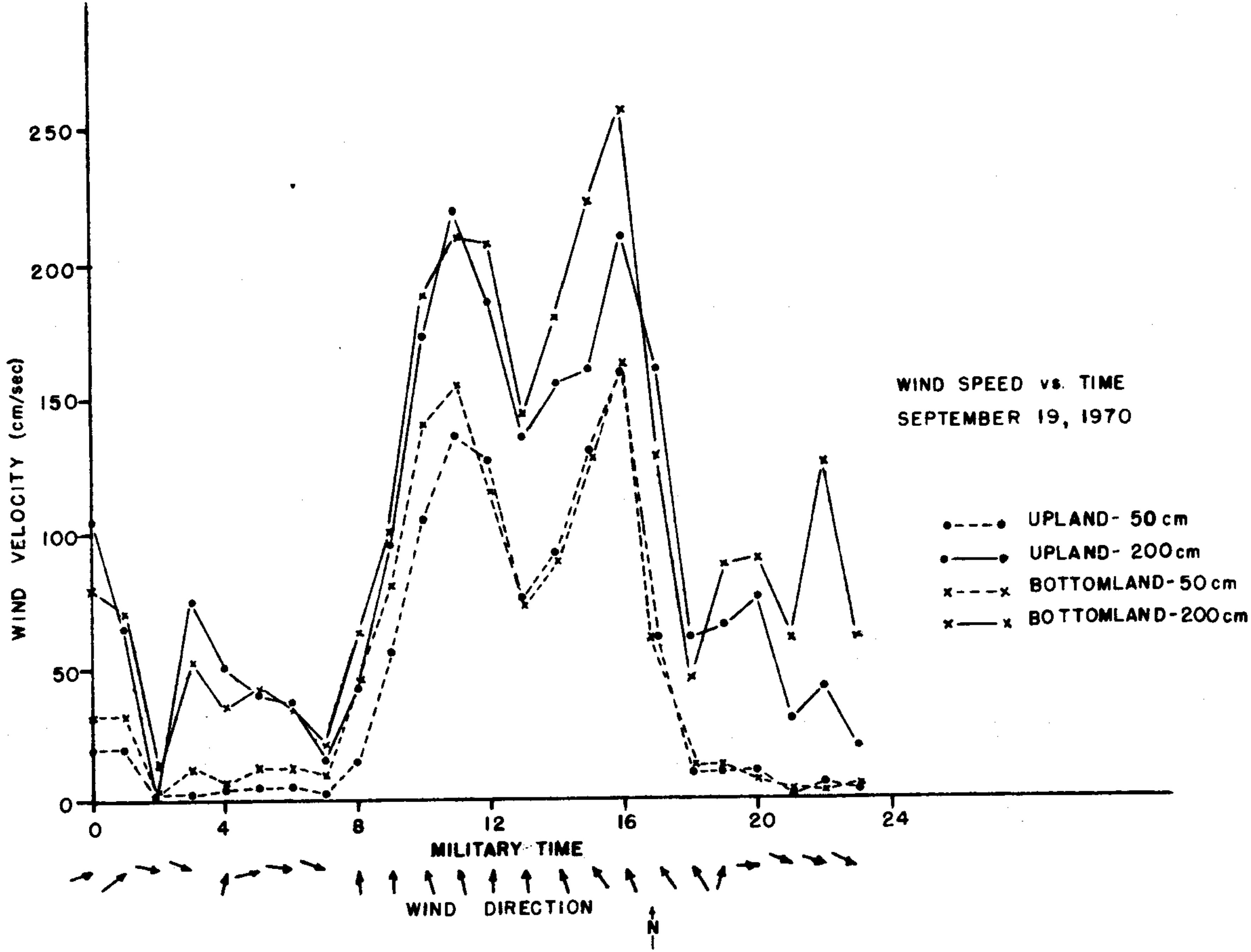

Fig. 2. Wind velocity and direction for September 19, 1970.

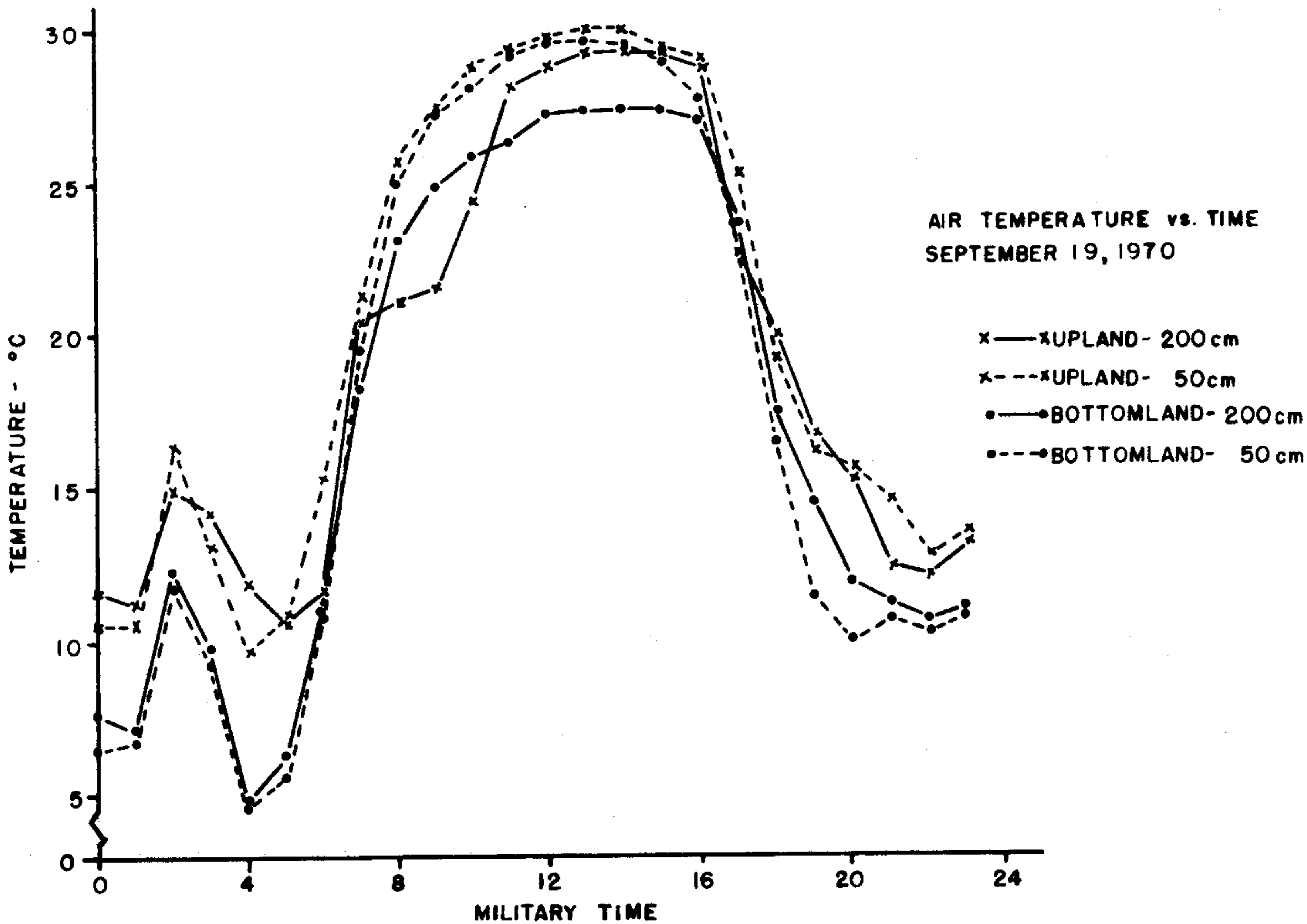

Fig. 3. Air temperature for September 19, 1970.

200 cm levels, was greater over the bottomland. This also suggested that the sensible heat transfer to the atmosphere was less for the bottomland.

Soil Temperature

Temperature, both aboveground and belowground level, was obviously dynamic with diurnal variations of periodic nature and cyclic with respect to seasonal changes. Temperature changed with respect to elevation both aboveground and belowground level. A tall deep-rooted plant, for instance, may have had a large temperature range in its environment from the bottom of the root zone to the ground surface and then upward to the top of the plant. The measurement and prediction of soil heat flow and temperatures should be of interest to the ecologist.

The heat flow equation, described in numerous texts dealing with partial differential equations, has been applied to the modelling of soil temperature. This equation states

$$C \frac{\partial T}{\partial t} = \frac{\partial}{\partial z} (\lambda \frac{\partial T}{\partial z}) \tag{1}$$

where C is volumetric heat capacity in cal/cm^3, and λ is thermal conductivity in cal/cm/second, and soil temperature, T, is in °C, and z is depth below the ground surface in cm. If the assumption is made that the soil medium is homogenous then isotropic equation (1) becomes

$$\frac{\partial T}{\partial t} = a \frac{\partial^2 T}{\partial z^2} \tag{2}$$

with the recognition that $a = \frac{\lambda}{C}$ where a is called the thermal diffusivity and has the units cm^2/second.

The separation of variables technique demonstrates that solution of the heat flow equation may have summations of the typical terms.

$$\begin{array}{l} k_1 \; e^{-k_2 z} \; \sin k_2 \; t \\ \vdots \qquad\quad \vdots \\ k_3 \; e^{-k_2 z} \; \cos k_2 \; t \end{array} \qquad (3)$$

k_1 through k_3 are coefficients often involving initial temperature conditions or indices of summations which lead to harmonics.

Van Wijk (1965) illustrates a typical model or solution to the heat flow equation:

$$T\ (z,t) = \overline{T} + TA \cdot \exp[(-z/D)\ \sin\ (\omega t + TO - z/D)] \qquad (4)$$

This expression assumes the following:

(i) Homogenous isotropic medium.

(ii) $T\ (\infty,\ t) = \overline{T}$

(iii) Soil temperature may be described as a simple sine function.

$\overline{T}$ is the average soil temperature in C° usually assumed to be the same at all depths (Wierenga et al. 1969). TA is the amplitude of the surface or uppermost temperature wave in C°. ω is the radial frequency in radians. TO is a constant which was selected to make the term $\sin(\omega t + TO - z/D) = +1$ when the surface or uppermost temperature was at its maximum. D is defined as the damping depth in cm and is a parameter which should be useful in quantitatively explaining the effect of soils, vegetation, and resource management on the temperature regime of a soil profile.

Equation (4) is similar to the first term of a typical series solution to equation (1), the heat flow equation, but differs because of the quotient $\frac{z}{D}$ which appears in both the exponential and the sine functions. $\frac{z}{D}$ cannot appear both places when a separation of variables technique is used to solve equation (1).

Equation (4) has obvious intuitive meaning. In words, it says that the soil temperature and depth at any time are equal to the average temperature plus a fraction of the amplitude of daily or yearly variation, as influenced by depth and time through an exponential function and a sine function.

Soil temperature courses were estimated for the September 19, 1970 upland site using equation (4). The average of all soil temperatures recorded during the 24 hour period was 18.93°C; the amplitude based on the 3 cm depth was 12.7°C. TO was selected so that the maximum temperature at 3 cm occurred at 13:00. Fig. 4 and 5 show a comparison of estimated and measured soil temperatures for September 19, 1970. Deviations from estimated to measured soil temperatures range up to 8°C with obvious discrepancies in phase. The fit might be improved by including an additional term with its harmonic. An additional term would not be hard to process with a modern high-speed computer.

Equation (4) indicates that the maximum or minimum temperature at an arbitrary depth z will occur when the sine function is either +1 or -1. Then for the amplitude A is

$$A = 2 \cdot TO \cdot \exp\left(-z_2 \sqrt{\frac{\omega}{2\alpha}}\right), \quad D = \sqrt{\frac{2\alpha}{\omega}}$$

The ratio of amplitudes at two depths z_1 and z_2 is

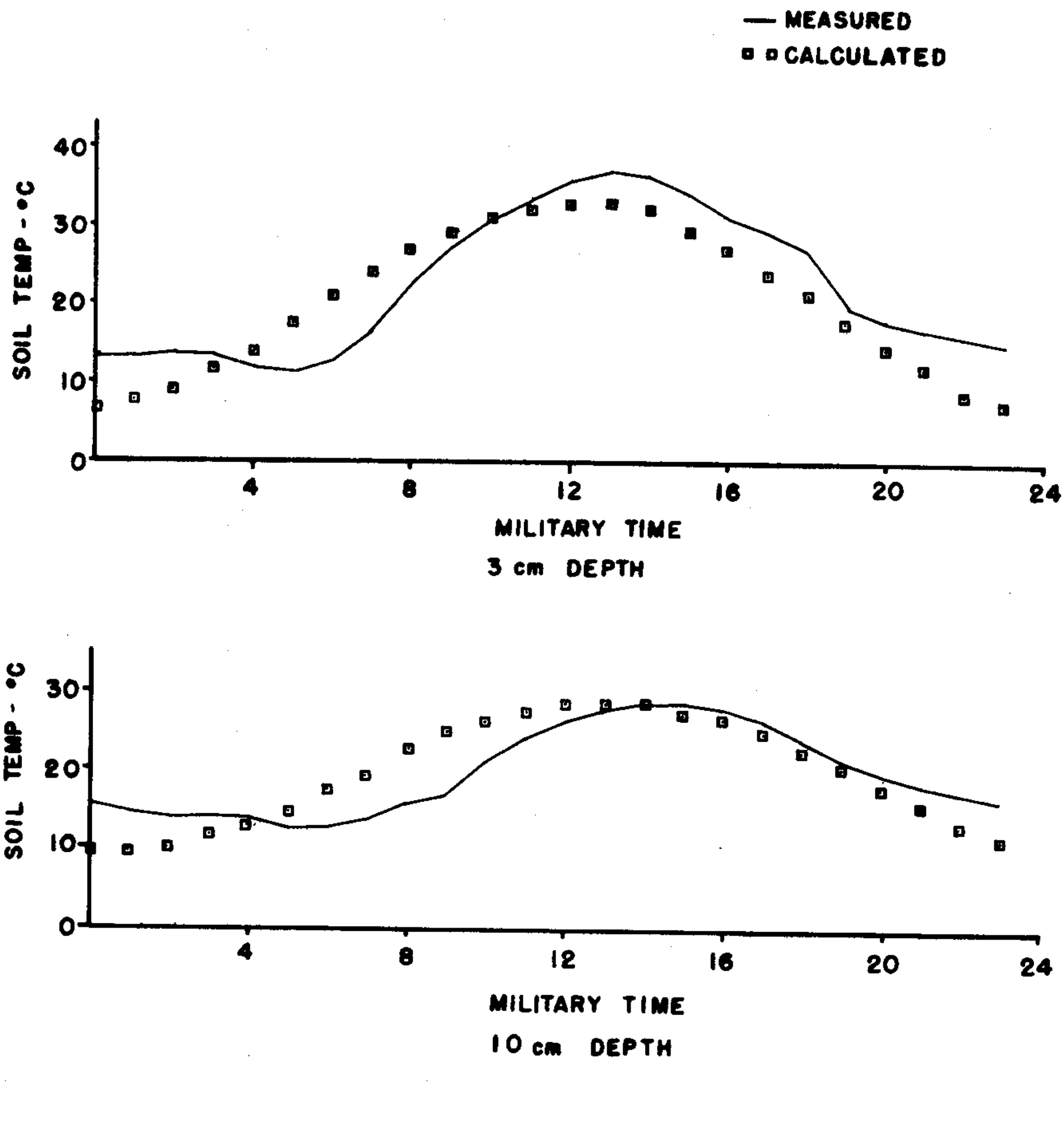

Fig. 4. Measured and calculated soil temperature courses for upland site at Pawnee Site, September 19, 1970.

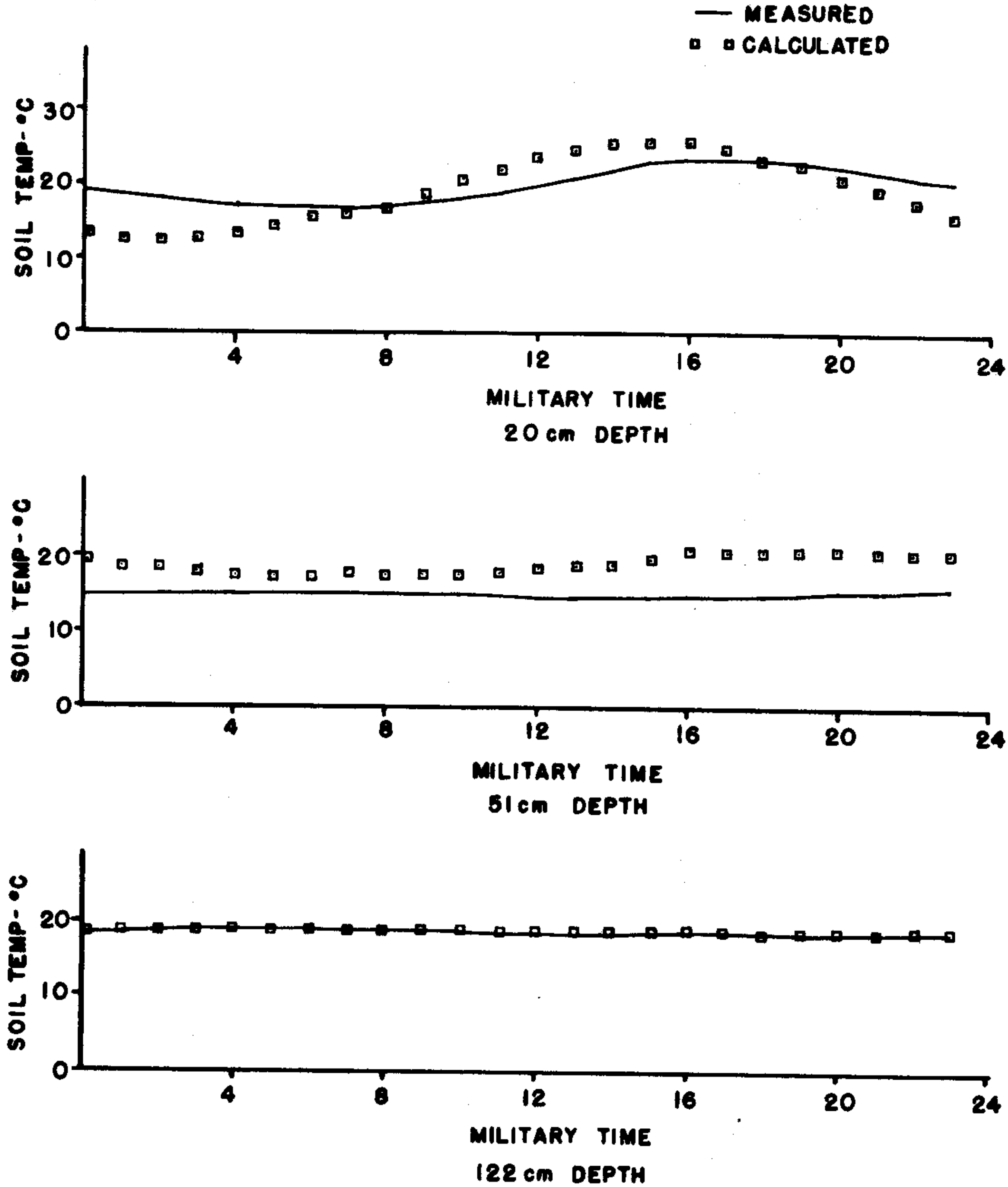

Fig. 5. Measured and calculated soil temperature courses for upland site at Pawnee Site, May 19, 1970.

$$\frac{A_1}{A_2} = \left| \frac{\exp\left(-z_1 \sqrt{\frac{\omega}{2\alpha}}\right)}{\exp\left(-z_2 \sqrt{\frac{\omega}{2\alpha}}\right)} \right|$$

and

$$\alpha = \frac{\omega}{2}\left(\frac{z_2 - z_1}{\ln \frac{A_1}{A_2}}\right)^2 \qquad (5)$$

Equation (5) was used to calculate values of the thermal diffusivity α for May 19, 1970 for both lightly and heavily grazed sites. Fig. 6 shows α is much larger for heavily grazed grassland than for lightly grazed grassland at lower depths and was similar at the 3 cm depth. Wierenga et al. (1965) attributes most of the change in α in a soil profile to variations in soil moisture.

Exp $(-z/D)$ reduces the amplitude of temperature variations with depth, and the term $-z/D$ in the sine function has the effect of "lagging" the soil temperature course at lower depths.

The damping depth was calculated from soil temperature measurements in the following manner. For a given depth the difference between maximum and minimum temperatures in a day may be written from equation (4) as follows:

$$\begin{aligned} Tmax - Tmin &= \overline{T} + TA \cdot e^{-\frac{z}{D}} - \overline{T} + TA \cdot e^{-\frac{z}{D}} \\ &= 2\ TA \cdot e^{-\frac{z}{D}} \end{aligned}$$

$$\ln\,(Tmax - Tmin) = \ln 2 + \ln TA - \frac{z}{D}$$

Therefore:

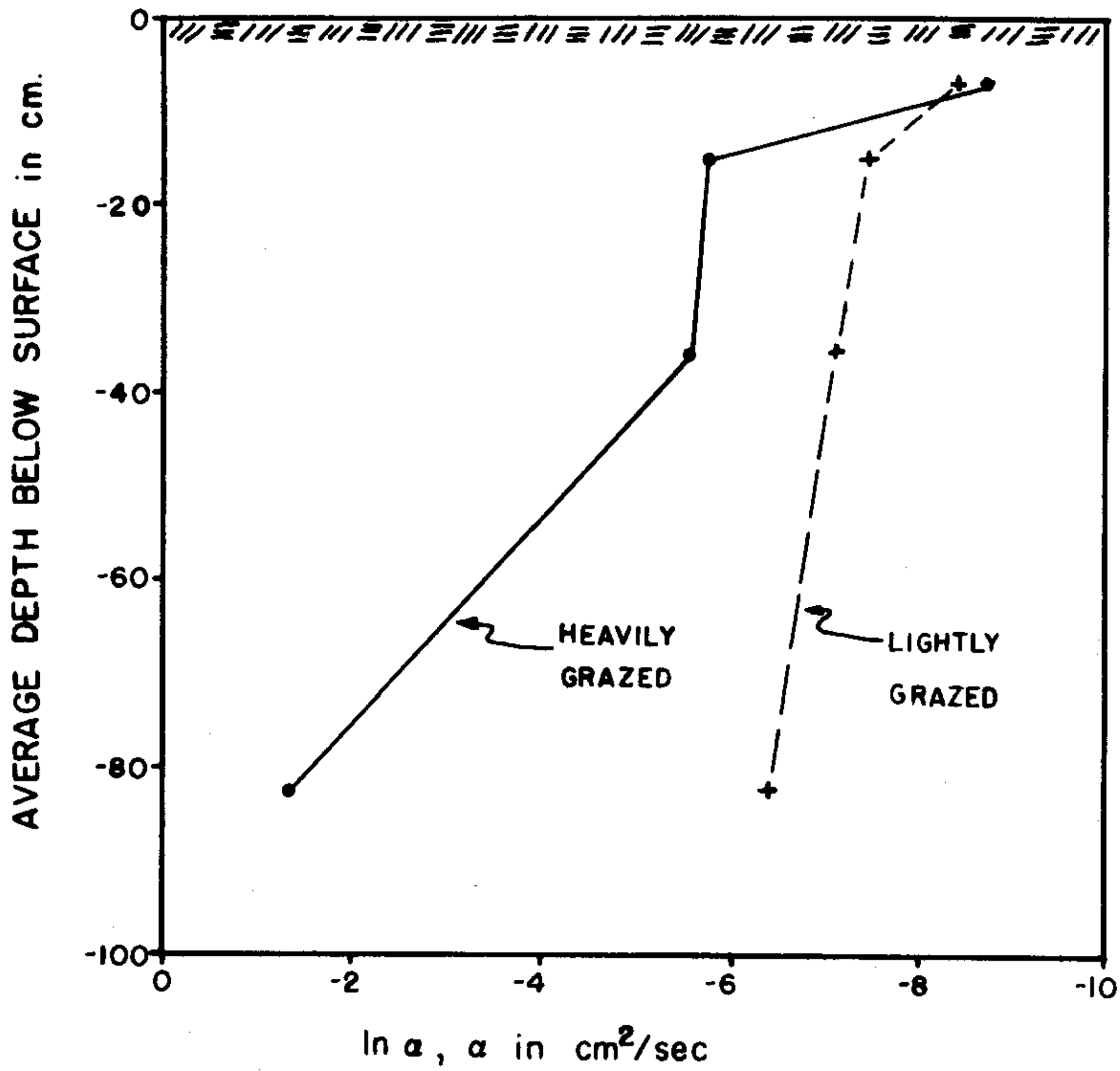

Fig. 6. Variation in thermal diffusivity with depth for two grazing treatments, Pawnee Site, May 19, 1970.

$$\ln (Tmax - Tmin) = \ln 2 + \ln TA - \frac{z}{D} \quad (6)$$

The slope of a plot of ln(Tmax - Tmin) and z is then $-\frac{1}{D}$. A least squares approach was used to calculate D for measurements taken in May and September 1970 on the Pawnee Site (see Table 2).

The damping depth "D" has physical significance because it may be noted that the amplitude of temperature fluctuations had been reduced to 36% of the surface variation when at $z = D$ and at $z = 3D$ the fluctuations are only 4.7% of surface values. Differences in upland and bottomland damping depths can be attributed to the differences in the vegetative cover. The bottomland has a more dense vegetative cover and greater litter. This boundary limits the heat flow into and out of the soil profile by controlling net radiation, sensible heat transfer (see radiation discussion p. 6) and evaporation. Also, differences in damping depths were strengthened by noting the upper soil temperature profile fluctuations shown in Fig. 7.

IV. LYSIMETRY

During the period of this report, final review and approval were given the lysimeter. Following purchase of materials and equipment, construction began in May 1970 and is presently nearing completion.

Briefly, the lysimeter is a conventional weighing type which utilizes a beam scale to counter-balance most of the soil weight and an electronic load cell to detect minute weight fluctuations due to evapo-transpiration. To represent the sparse prairie grassland, a core of soil ten feet in diameter and four feet in depth was selected. The core is relatively undisturbed (in situ), as is the perimeter area of the site. Further description includes

Table 2. Calculated values of "D", the damping depth 1970, Pawnee Site Grassland Biome.

Day	Location	D in cm
5-19-70 (1)	Lightly Grazed	28.1
5-19-70 (2)	Heavily Grazed	28.2
9-17-70 (1)	Upland Site	25.4
9-17-70 (2)	Bottomland Site	24.0

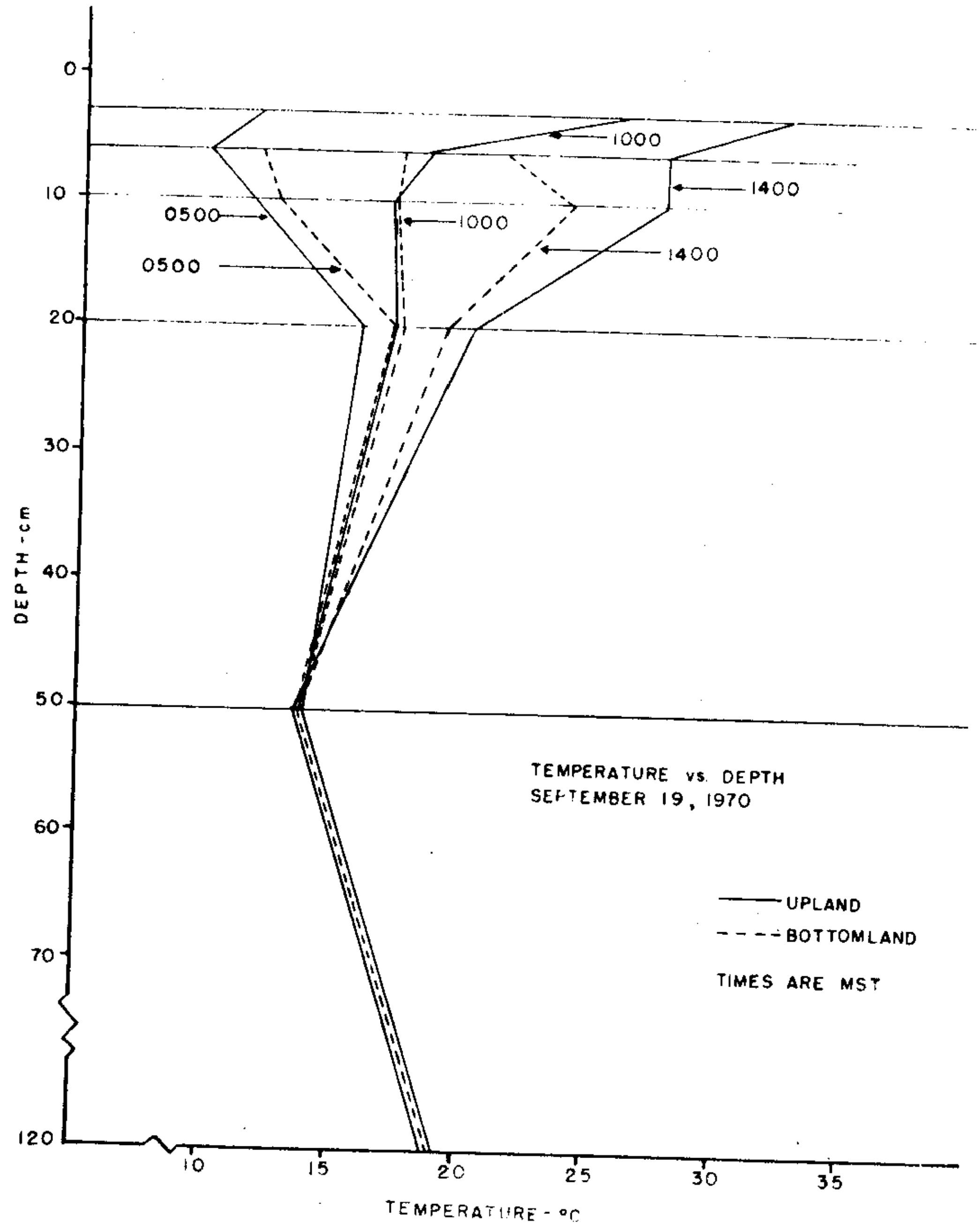

Fig. 7. Soil temperature profile for September 19, 1970.

a sensitivity of one part in one hundred thousand which allows detection of four-tenths of a pound. This was equivalent to one-thousandth of an inch of water loss from the surface. Unnatural surface area of the retainer rim, gap and soil container rim, equals approximately two percent of the total area. The volume of air beneath the soil container has been minimized to less than 50% of the soil core volume. This was done by placing the counter-balance scale beams in an access tunnel.

Upon completion of construction, early winter will entail "tuning" the counterbalance mechanisms, inserting the load cell and connecting it to a voltage source and data recording device and calibrating the system by adding known weights to the surface. It is anticipated that the lysimeter will be giving evapotranspiration data in the early spring (1971). Initial data manipulation will be to compare evapotranspiration data from the lysimeter to evapotranspiration estimates derived from corresponding meteorological data. A correction will be obtained which will aid in substantiating evapotranspiration estimates derived from the meteorological data acquisition system.

V. SAMPLING REQUIREMENTS FOR SHORT-PERIOD MEANS OF METEOROLOGICAL PARAMETERS

Investigations of the number of observations required for short-period means of various meteorological parameters have been initiated. Little has been written on this question; however, it presents a real problem to the investigator faced with the decision of an adequate sample size, yet one small enough to keep data collection and reduction problems at a minimum. This is a particularly important decision when operating in remote areas, such as the comprehensive sites of IBP.

The most common example of sampling to determine short-period means is the averaging of the maximum and minimum values during a period, especially that of a day. The adequacy of this type of sampling is, of course, dependent upon many factors. Important among these are the precision requirement and the variability of the element being investigated.

The present study has been initiated by considering the estimation of hourly means of air and soil temperatures, solar radiation, and wind movement. It is planned to also investigate daily means. The data acquisition system at the Pawnee Site provides a true value, within the accuracy of the sensor and electronic equipment of the meteorological elements. Sample sizes selected for this study were 1, 2, 4, 6, 12, 15, 20, 30, and 60 observations per hour, with the 60 observations per hour considered as the true value because observations are integrated over one minute periods. The sample sizes were chosen so that the intervals between observations could be constant for any given sample; for example, observations were taken every 10 minutes for a sample size of six.

An example of the comparison of hourly means of solar radiation, using sample size of 60 vs 2 and 60 vs 12, are shown in Fig. 8 and 9. The observations are for 97 hourly periods from selected days in May and June 1970. These figures show, in a general way, the closer approximation to the true value as the sample number increases. The decision of the number of observations required for any variable and experiment will be dependent upon the risk one is willing to take that the estimates are within certain limits of the true value. The statistical level of significance can be used to represent this risk, and this is the form in which the completed results will be expressed.

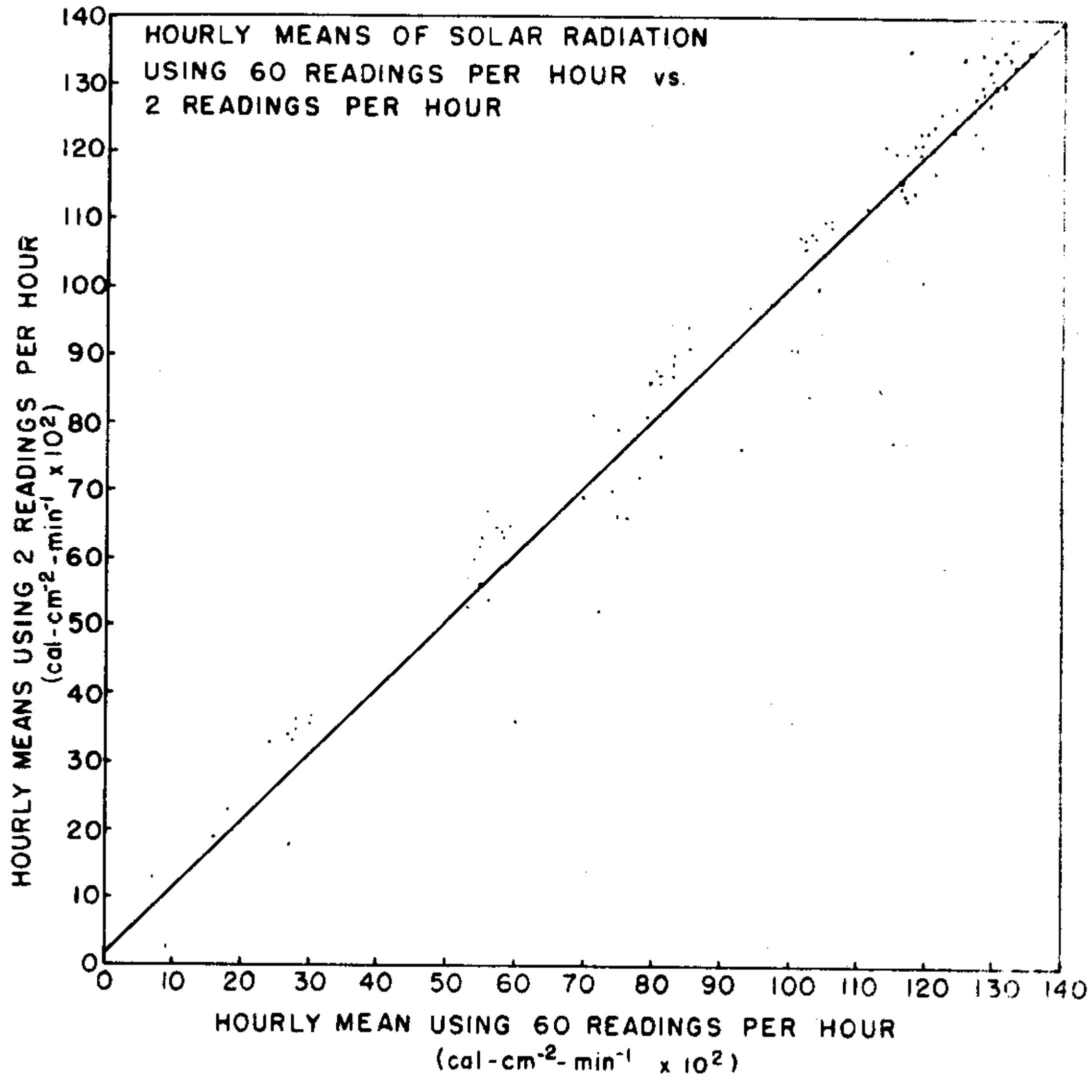

Fig. 8. Hourly means of solar radiation using 60 readings per hour vs 2 readings per hour.

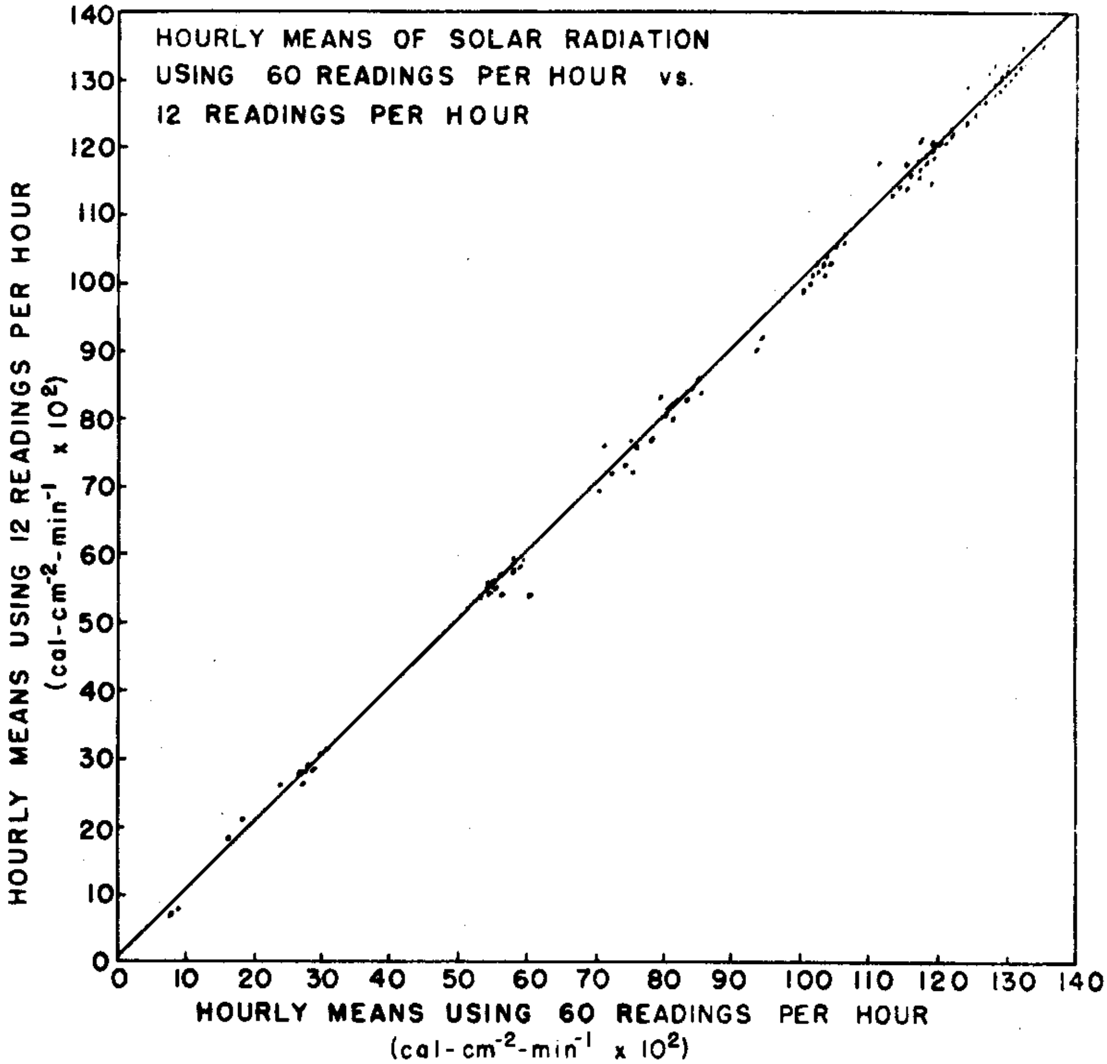

Fig. 9. Hourly means of solar radiation using 60 readings per hour vs 12 readings per hour.

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APPENDIX I

FIELD DATA

Meteorological Data

Meteorological data collected at the Pawnee Site are automatically recorded on magnetic tape at 200 bits per inch in binary mode. Thirty-six channels of meteorological information and five channels of ancillary information are recorded minutely. The signals from the sensors are received as millivolts and are converted to four digit integer counts before being recorded. These field data tapes, Grassland Biome Data Set A2U700B, are sent to the Grassland Ecology Research Laboratory in Fort Collins where they are packed on new tapes in the same format but at 800 bits per inch. This is accomplished by program JVN001A (Program Documentation Series #7). These 800 BPI tapes constitute Grassland Biome Data Set A2U705B and are saved. The 200 BPI tapes are released for further use.

At both densities, the channels contain parameters as follows:

Channel	Treatment[a/]	Parameter	Level (cm)
01	A	Air Temperature	200
02	B	Air Temperature	200
03	A	Air Temperature	50
04	B	Air Temperature	50
05	A	Soil Temperature	-122
06	B	Soil Temperature	-122
07	A	Soil Temperature	-51
08	B	Soil Temperature	-51
09	A	Soil Temperature	-20
10	B	Soil Temperature	-20
11	A	Soil Temperature	-10

Channel	Treatment[a/]	Parameter	Level (cm)
12	B	Soil Temperature	-10
13	A	Soil Temperature	-6
14	B	Soil Temperature	-6
15	A	Soil Temperature	-3
16	B	Soil Temperature	-3
17	A	Soil Heat Flux	-5
18	B	Soil Heat Flux	-5
19	A	Wind Speed	50
20	B	Wind Speed	50
21	A	Humidity	200
22	B	Humidity	200
23	A	Humidity	50
24	B	Humidity	50
25	A	Net Radiation	200
26	B	Net Radiation	200
27	A	Long Wave Radiation	200
28	B	Long Wave Radiation	200
29	T	Barometric Pressure	300
30	A	Reflected Short Wave Radiation	200
31	B	Reflected Short Wave Radiation	200
32	T	Total Incoming Radiation	300
33	A	Wind Direction	200
34	B	Wind Direction	200
35	A	Wind Speed	200
36	B	Wind Speed	200
37		Minute	
38		Hour	
39		Day	
40		Month	
41		Experiment Code	

a/ Treatment Key

A = Lightly Grazed
B = Heavily Grazed
T = Representative of Both A and B

Data set A2U705B contains data for the following periods in 1970.

1 January	-	3 January
27 February	-	4 March
22 March	-	30 March
18 May	-	24 May
1 June	-	6 June
9 June	-	10 June
4 August	-	21 August
31 August	-	8 September
16 September	-	28 September
30 September		
1 October	-	26 October