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JPL Field Measurements at the Finney County, Kansas, Test Site, October 1976: Meteorological Variables, Surface Reflectivity, Surface and Subsurface Temperatures

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PREFACE

The work described herein was performed by the Earth and Space Sciences Division of the Jet Propulsion Laboratory.

CONTENTS

ABSTRACT

Data collected by JPL at the Finney County, Kansas test site as part of the Joint Soil Moisture Experiment (JSME) during October 9-14, 1976 is presented here, prior to analysis, to provide all JSME investigators with an immediate source of primary information. The ground-truth measurements were taken to verify and complement soil moisture data taken by microwave and infrared sensors during aircraft overflights on October 13 and 14. Measurements were made of meteorological variables (air speed, temperature, relative humidity and rainfall), surface reflectivity, and temperatures at and below the surface.

INTRODUCTION

This document contains the data collected by the JPL Earth Applications and Climatology group at the Finney County, Kansas test site as part of the Joint Soil Moisture Experiment (JSME) during October 9 - 14, 1976. These data have not yet been analyzed. The purpose here is to record the original data intact, providing an immediate source of primary information to all JSME investigators. A companion paper will present the JPL microwave ground-based radiometric observations and surface truth (Njoku and Yamane, 1977)

The data consist of measurements of meteorological variables (air speed, temperature, and relative humidity), surface reflectivity, and temperatures at and below the surface. All these parameters are listed in the appendices and a description of the data gathering methods precedes them. The next section gives the location and particulars of the sites investigated.

These ground-truth measurements are desirable to complement and verify the soil moisture data acquired from infrared and microwave measurements that were made by aircraft flying over the test sites on two days: Oct. 13th and 14th. The data gathering effort was facilitated by excellent weather (nearly clear skies and no precipitation during the period). All objectives were achieved without difficulty, the instruments performed well and a substantial amount of data was acquired.

SITE DESCRIPTION

The fields chosen by JPL for ground truth data collection for the Joint Soil Moisture Experiment in Finney County, Kansas are indicated

in Fig. 1. There was a total of 17 sites along flight lines 1, 2 and 4 representing the various types of fields found in the JSME test site. The instruments used at each of the various sites are listed in the legend accompanying Fig. 1. A description of the individual sites follows.

Site 1: Newly Planted Wheat Field

Eastern edge of field 129a, 7 - 8 meters in from north-south road, nearly uniform north-south trending furrows approximately 10 cm high with newly planted winter wheat 5 - 8 cm high.

Site 2: Newly Planted Wheat Field

Northern edge of field 129a, about 1.5 meters from main road, east-west trending furrows, with some debris, winter wheat, 5 - 8 cm high.

Site 3: Wheat Stubble Field

Field just east of 129a, 7 - 8 meters in from north-south road, wheat stubble, dry, yellowed, 25 - 50 cm high, some upright, some matted down with 5 - 10% green volunteer wheat.

Site 4A & B: Bare Field

Field just east of 129a and south of site 3 field, 7 - 8 meters in from north-south road, very sparse, dry, flattened milo stubble.

Site 5: Newly Planted Wheat Field

Northeastern quarter of field 129d, 7 - 8 meters from main road, located in clay pan, newly planted, diagonal furrows, no wheat visible, some debris and green weeds.

Site 6: Newly Planted Wheat Field

Northwestern quarter of field 129d, 7 - 8 meters from main road, east-west trending furrows with new winter wheat, 5 - 8 cm high, out of clay pan.

Site 7: Newly Planted Wheat Field

Western edge of field 38b, 7 - 8 meters from north-south road, diagonal furrows, new winter wheat, 5 - 8 cm high.

Site 8A: Grassy Field

Field just west of 50d, dense mixture of dried and green grass, 25 - 40 cm high.

Site 8B: Newly Planted Wheat Field

About 7 - 8 meters in from western edge of field 50d, north-south trending furrows, newly planted, no wheat visible. Furrow orientation site (A through G) was in the vicinity of site 8B.

Site 9: Grassy Field

Southern edge of field 31, mixed dry and green grass starting about 7 - 8 meters in from main road.

Site 10: Newly Planted Wheat Field

Eastern edge of field 30A, 7 - 8 meters from north-south road. Newly planted diagonal furrows, no wheat visible.

Site 11A & B: Milo Stubble Field

Western edge of field 27c, 7 - 8 meters from north-south road. Milo (a feed grain) scrub, semi-dried, 30 - 75 cm high, 40 - 50% bare, dried, cracked soil, some grey-green weeds and bushes.

Site 12: Mature Milo Field

Southwestern edge of field 26, about 60 cm in from edge. Solid, unharvested milo with heads of reddish brown grain, 1 - 1.5 meters high.

Site 13: Wheat Stubble Field

Field across the main road and south of field 26, 7 - 8 meters from main road, dried, yellowed wheat stubble, 25 - 50 cm high in rows with 30 - 40% green volunteer wheat in between.

Site 14: Newly Planted Wheat Field

Eastern edge of field 18, 7 - 8 meters from north-south road, diagonal furrows with newly planted winter wheat, 10 - 13 cm high.

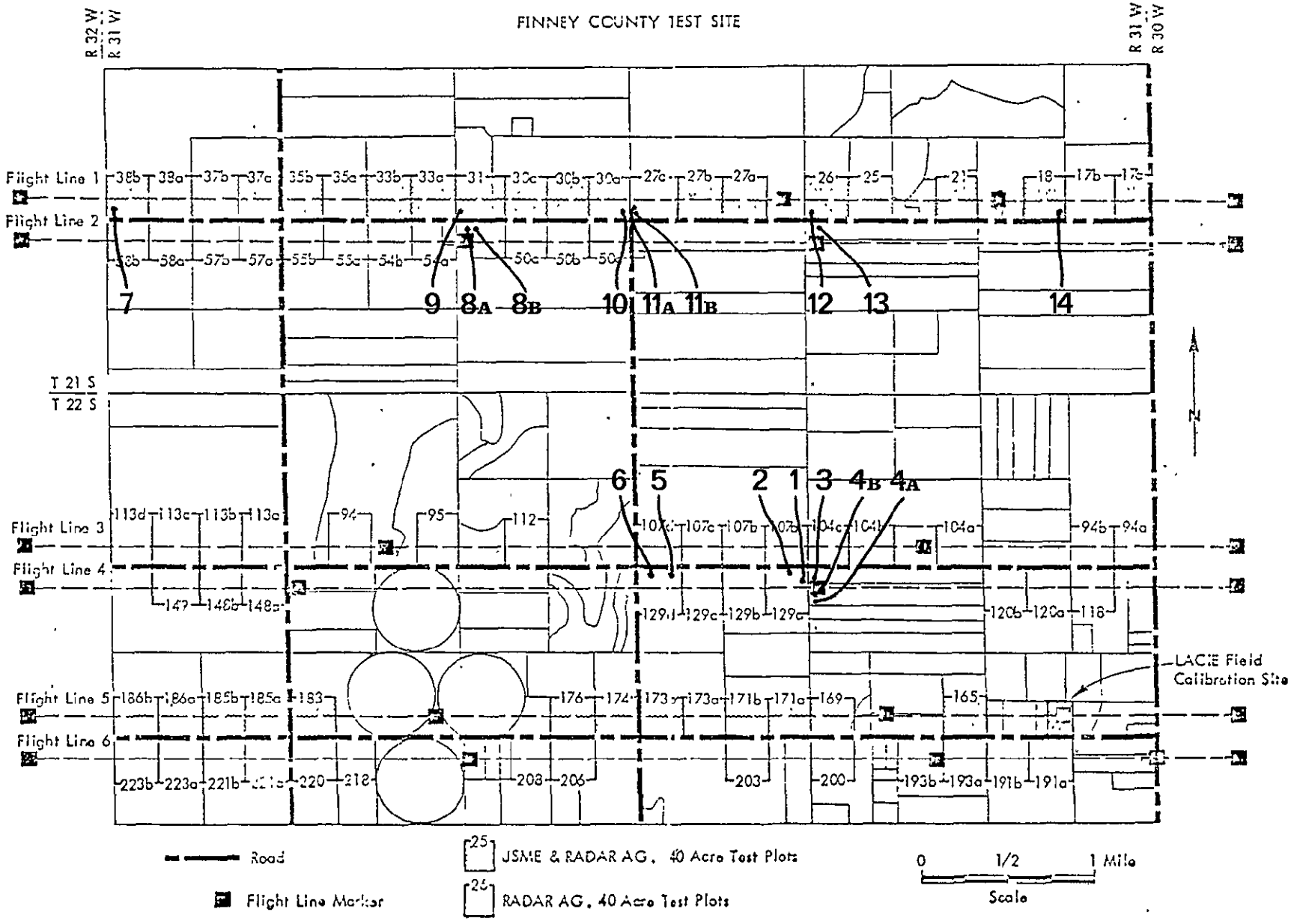


Fig. 1. Map of JSME Finney County, Kansas, test site. JPL sites in bold-faced numbers

FIGURE 1 LEGEND

SITE	INSTRUMENTATION
1	PFRS, PRT-5, YSI, Van
2	PFRS, PRT-5
3	PFRS, PRT-5, YSI
4A	PFRS, PRT-5, Portable Weather Station (7 levels)
4B	PFRS, PRT-5, Portable Weather Station (1 level)
5	PFRS, PRT-5, YSI
6	PFRS, PRT-5, YSI
7	PRT-5, YSI, Van
8A	PFRS
8B	PFRS, PRT-5, YSI, Furrow Orientation Site, Van
9	PRT-5
10	PRT-5, YSI, Van
11A	PFRS, PRT-5
11B	PFRS, PRT-5
12	PFRS, PRT-5, Van
13	PFRS, PRT-5
14	PRT-5, YSI, Van

PFRS - Portable Field Reflectance Spectrometer

PRT-5 - Barnes Precision Radiation Thermometer

YSI - Yellow Spring Instr. Co. Temperature Probes

Van - JPL's microwave van.

DATA ACQUISITION

Meteorological Variables (One Level)

A mechanical weather station (manufacturer, Meteorology Research, Inc.) set to collect data at an elevation of 1.5 meters was located east of field 129a (site #4B) about 45 meters north of the portable micrometeorological system described in the next section. Mounted on a tripod, the weather station was placed about 7 - 8 meters east of the north-south dirt road on a field sparsely covered with dry, flattened milo stubble next to a wheat stubble field.

The mechanical weather station measures four meteorological parameters: wind speed, air temperature, relative humidity, and rainfall. The station is powered by 4 flashlight batteries and records data on a strip chart.

The meteorological sensors are: wind speed, a 3 cup anemometer with an operating range from about 1 km/hr to over 160 km/hr; air temperature, a shielded bimetallic coil with an operating range from -68°C to 49°C; relative humidity, a moisture-sensitive element with an operating range from 0 to 100%; rainfall, a cylindrical (tipping bucket) rain collector with a diameter of 20 cm and a height of 60 cm. The latter sensor was placed on the ground a distance of ten yards from the station.

The data are given in Appendix A. Included are: date and time, air temperature (T) in °C, wind speed in kilometers per hour, and relative humidity (Q) in percent. No rain fell during the period.

Meteorological Variables (Seven Levels)

A portable micrometeorological weather station and recorder (developed by JPL) were set up to collect data at site 4A, 7 - 8 meters east of field 129a and the north-south road.

The area around the site was relatively flat and free of obstructions. On the other hand, the surface area was not of uniform roughness: the fetch from the west passed over a nearly-homogeneous, furrowed surface of newly planted wheat; while, the fetch from the east passed over an area that included fields scattered with crop debris or covered with a wheat stubble about 25 cm high.

The weather station measures the air speed, temperature, and humidity at 7 levels over an altitude range of 8 meters. The levels are at: 1/8, 1/4, 1/2, 1, 2, 4, and 8 meters. The sensors are a psychrometer-anemometer pair, one pair for every level; each instrument is at the end of a 1 meter rod that is attached to a mast a little over 8 meters long (Figure 2). The anemometers are the three-cup type, about 9 cm high, 5 cm in diameter and with rotor arms 7.5 cm long: they are lightweight, durable, and weather-proof. The psychrometers consist of two thermistors (Yellow Springs Instrument, YSI #44202) enclosed in a small metal box about 17.5 cm long and 5 cm high. The YSI probes have a range from -5°C to 45°C and an accuracy of ± 0.15°C. One thermistor measures the dry-bulb air temperature; the other is covered by a cotton wick that is supplied with water from a small reservoir attached to the bottom of the case and this thermistor measures the wet-bulb air temperature. The thermistor couple is ventilated by a draft from a small fan set in the front of the case. The instruments

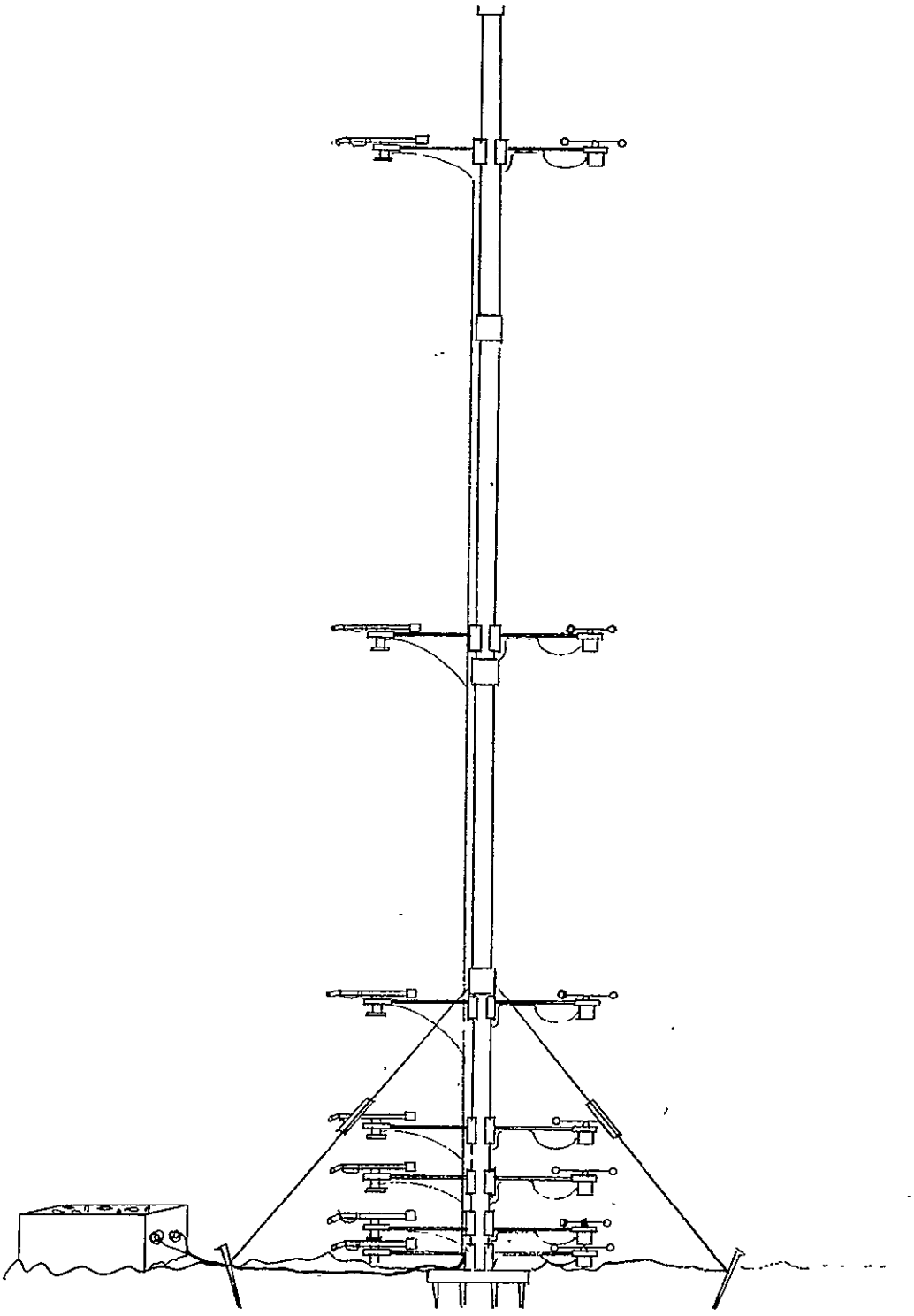


Fig. 2. Portable weather station, seven levels

are connected by cables to an electronic recorder and the entire system is powered by a 6 volt battery. The data are recorded and printed on paper tape.

Data were registered from the evening of October 11 until the mid-afternoon of October 14. The data consisted of 16 minute averages of dry-bulb and wet-bulb temperatures (in °C) and rotational speeds (in RPM) of the anemometer cups. (The cup RPM is linearly related to the wind speed as shown below.) The data were printed at 16 minute intervals when the system was operating.

Some notes on the data follow. Data are missing on the night of the 11th and the morning of the 12th because an on-off switch malfunctioned. The problem was corrected around noon on the 12th and the record is complete from then on. Anemometer 6 was damaged on the morning of the 12th and ceased working thereafter, and in anemometer 3 a diode failed causing a loss of the last two hours of data on the 14th. Electronic problems caused dry-bulb thermistor 5 to read too low most of the time and, for a few intervals, wet-bulb thermistors 4 and 5 and dry-bulb thermistor 4 to record incompletely or not at all. Care was taken to calibrate all instruments before and after the experiment. On the afternoon of the last day some psychrometers showed a calibration drift. This required correcting the data gathered after 1200 on October 14. The corrections are listed in the table below.

Of the 185 records obtained, all have <u>at least</u> 5 levels of wind speed and temperature data.

Appendix B displays the data from October 11 at 1827.50 to October 14 at 1510.14. The time is presented in hours, minutes, and seconds and is printed at the bottom of each record. (Note that the 1st digit is printed far to the left under the column listing triples of integers.) The data are grouped in threes for each level with level 7 at the top of the record. The wet-bulb temperature is listed first, the dry-bulb temperature is second, and the rotational speed of the anemometer cups is third.

A table is given below listing the height of each level, the linear calibration curves relating cup RPM to wind speed, and the temperature corrections to account for calibration drifts after 1200 on October 14.

LEVEL	HEIGHT (METERS)	A_o^*	A_1^*	T_{dry} (°C)	T_{wet} (°C)
1	0.125	1.0529	0.0263	+ 0.5	+ 0.3
2	0.25	0.8872	0.0257	0.0	0.0
3	0.5	0.6946	0.0267	+ 0.5	0.0
4	1.0	0.7366	0.0266	+ 0.3	+ 0.2
5	2.0	0.7100	0.0259	0.0	0.0
6	4.0	0.6890	0.0270	0.0	0.0
7	8.0	0.8066	0.0241	0.0	0.0

*A_o and A_1 are regression constants used to convert cup RPM (R) to wind speed (U) by $U = A_1R+A_o$. The linearity of the cup anemometers was tested in a wind tunnel for speeds up to 16 M/S (36 mph): as measured by the coefficient of determination (r^2), all anemometers were linear by at least 0.993 (r^2 = 1.000 denotes perfect linearity). The formula gives U in meters per second.

Surface Reflectivity

Surface spectral reflectance measurements were acquired with the JPL Portable Field Reflectance Spectrometer (PFRS) (Goetz et al., 1975) at eleven sites during the week of the mission. The PFRS is a completely portable field instrument which measures surface reflectivity in the wavelength region from 0.45 to 2.55 μm with moderate resolution ($\Delta\lambda/\lambda$ = 0.04 from 0.45 to 0.7 μm and 0.015 from 0.7 to 2.55 μm). First, the reflectance spectrum of the natural surface illuminated by the sun is taken, followed immediately by a spectrum of a standard (fiberfrax, a ceramic wool) placed over the surface in the same orientation. Each scan takes thirty seconds and the data are recorded on a digital cassette. Reduction of the data collected can be done on the same day using a PDP-8/E computer and Houston Instruments plotter set up in a motel. By taking a point-by-point ratio of the spectra of the surface and the standard, a bidirectional reflectance spectrum, independent of source and atmospheric conditions, and surface attitude, is obtained.

An average spectrum for each site was produced using between 4 and 9 individual spectra collected at each location. When there was significant variation of the surface reflectivity at a site due to vegetation, furrowing etc., an effort was made to obtain sufficient spectra to be representative of the entire site. The plots showing the average surface spectral reflectance at each site are presented in Appendix C. Percent reflectance is plotted as a function of wavelength from 0.45 to 2.55 μm. The water absorption bands at 1.4 μm and 1.9 μm are eliminated during the plotting.

Surface and Subsurface Temperatures

The ground surface radiation temperature was measured at 16 sites with a Barnes Precision Radiation Thermometer, Model PRT-5. This completely portable hand-held instrument measures the emitted radiation in the wavelength range 8 - 14 μm, and displays the equivalent blackbody temperature on a meter. It is specified to be accurate to 0.5°C. The temperatures were measured frequently enough throughout the day to establish the diurnal heating pattern of the surface.

The narrow field of view of the instrument (2°) caused a serious problem during the daylight hours. The furrowed surfaces of the newly planted fields had widely varying surface temperatures dependent upon the orientation of the furrow relative to the incident solar radiation. At some locations, the temperature varied as much as 30°C (for instance approximately 25° to 55°C) from the shaded to the sunny side of a furrow. An effort was made to take an integrated average over the surface, by slowly scanning across the furrows and mentally averaging the displayed temperatures. This process was occasionally made more difficult by having to change temperature range scales on the meter, the mid-range reading up to 45°C and the high range reading from 40°C upward.

Subsurface temperatures were determined by Yellow Springs Instrument Co. (YSI) temperature probes imbedded in the soil at depths of 2", 5", 10", and 15" below the mean surface. These probes consist of a thermistor temperature sensing element housed in a probe and attached to a plasticized vinyl jacketed shielded lead wire terminating in a phone plug. When these probes are plugged in, temperatures are read

directly from a YSI meter. These measurements and the PRT-5 surface temperature measurements were made simultaneously.

Both surface and subsurface temperatures were measured from the time of surface temperature minimum at pre-dawn on Oct. 13, throughout the day of Oct. 13 (during the JSME flights), through the night to the surface temperature minimum at pre-dawn on Oct. 14 (during the JPL flights), and on until the daytime heating had definitely been established. These data are presented in Appendix D.

In order to help assess the effect of the furrowing on the near surface heating, the temperature at the surface and at a depth of 2" was measured on the sides, top, and bottom of furrows oriented east-west and north-south. A diagrammetric sketch of a cross-section of the furrows with the location of the measurements is shown in Fig. 3. The temperatures were measured throughout the diurnal cycle, near JPL site 8B. These data are given in Appendix E.

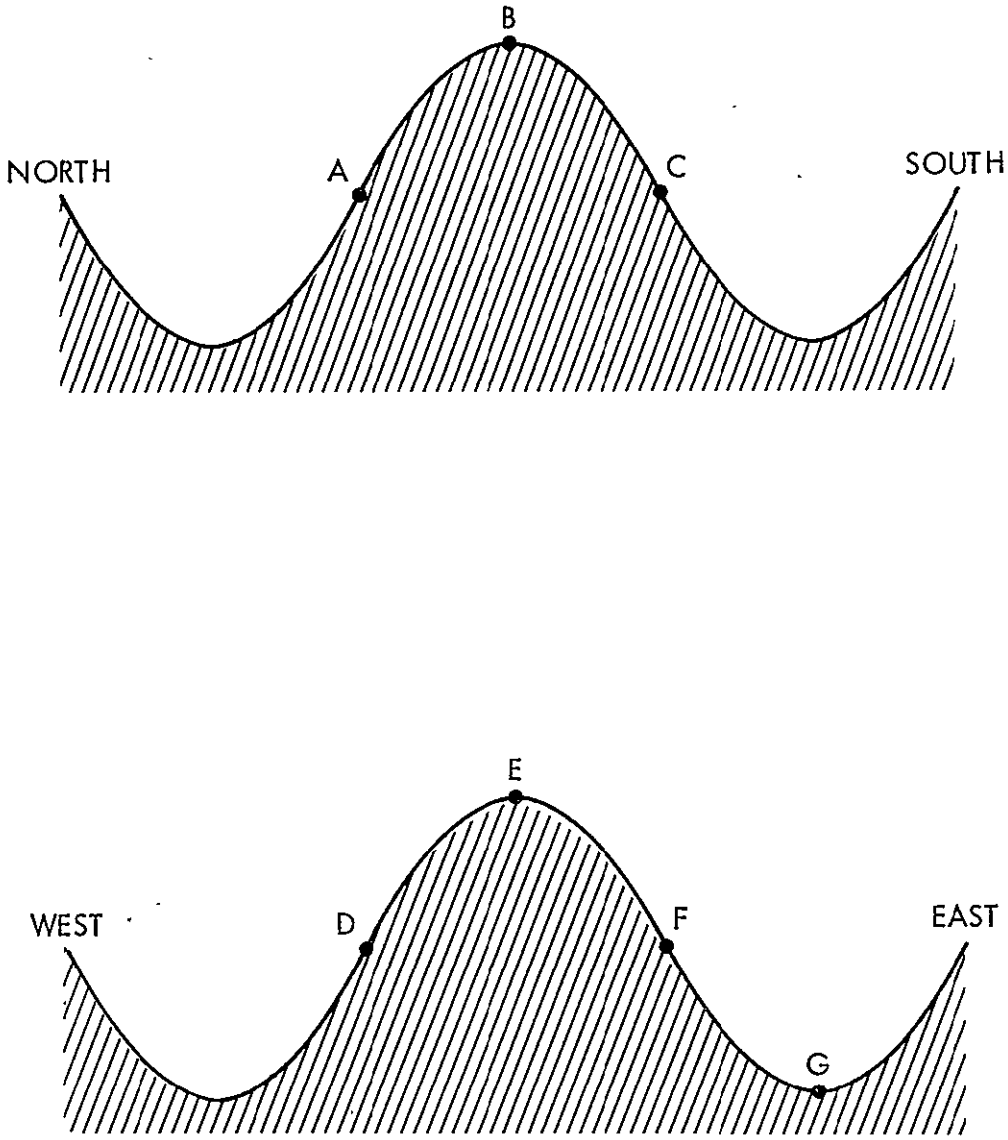


Fig. 3. Furrow cross-section showing positioning of temperature probes

ACKNOWLEDGEMENTS

Ted Buras of JSC was exceedingly helpful in establishing liaison with other experimenters, in site orientation, and in insuring that the entire experiment ran smoothly. Bill Waite of the Univ. of Arkansas gave us useful advice on site selection. Warren Rachwitz of JPL participated in developing and maintaining the equipment, and in the long hours of field measurements. Richard Machida of JPL helped develop the equipment, and did much of the data reduction.

This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract number NAS7-100, sponsored by the National Aeronautics and Space Administration.

APPENDIX A

METEOROLOGICAL VARIABLES:

ONE LEVEL

		T(^{o}C)	Q(%)	Wind Speed (km/hr)
10/11/76	1800	30.0	23	6.0
		28.5	26	4.0
		27.0	27	3.0
	1900	25.5	28	4.0
		22.0	31	5.5
		20.0	33	5.0
	2000	18.0	37	5.0
		17.5	39	3.0
		16.5	40	2.5
	2100	16.5	40	1.8
		16.5	42	2.5
		16.5	43	2.5
	2200	16.0	44	6.0
		15.0	45	3.5
		14.5	45	6.0
	2300	13.0	46	5.2
		16.0	47	6.5
		15.0	46	5.5
10/12/76	0000	13.0	48	5.2
		12.0	50	4.5
		12.0	52	5.0
	0100	10.0	54	5.2
		12.5	57	7.0
		11.0	58	5.5
	0200	9.5	61	6.5
		8.5	64	6.6
		9.0	66	7.2
	0300	8.5	67	8.4
		9.0	68	9.5
		8.5	68	12.0
	0400	9.5	68	15.0
		10.0	67	14.4
		9.0	67	14.8
	0500	9.0	66	15.0
		8.5	66	14.5
		8.0	67	13.3

APPENDIX A (continued)

	T(°C)	Q(%)	Wind Speed (km/hr)
0600	8.5	67	11.4
	8.5	67	12.0
	8.5	67	10.8
0700	8.0	67	12.3
	8.5	67	14.4
	8.5	67	18.0
0800	8.5	66	16.6
	9.5	65	19.0
	10.0	64	21.6
0900	12.0	63	24.0
	13.5	60	28.0
	14.0	59	29.5
1000	14.0	57	24.0
	15.0	56	31.5
	16.0	54	28.0
1100	16.0	53	31.8
	18.0	52	29.5
	18.5	50	29.0
1200	19.5	49	32.0
	20.5	47	32.0
	21.5	46	30.0
1300	22.0	44	30.0
	23.0	43	30.0
	22.5	42	31.0
1400	22.5	42	30.0
	22.5	42	29.0
	22.5	41	32.0
1500	22.5	41	30.0
	22.5	40	28.0
	22.5	40	31.0
1600	22.5	40	30.0
	22.5	41	25.0
	22.0	41	24.0
1700	22.0	41	22.0
	21.5	41	21.0
	21.5	41	20.5
1800	21.5	41	19.0
	21.0	42	17.0
	19.0	42	11.0
1900	17.5	44	6.5
	15.0	47	5.8
	14.5	48	3.7

APPENDIX A (continued)

		T(°C)	Q(%)	Wind Speed (km/hr.)
	2000	13.0	50	3.5
		13.0	52	4.2
		12.5	53	4.5
	2100	11.0	56	3.0
		11.0	58	4.8
		11.0	58	4.5
	2200	10.5	59	3.4
		10.5	59	3.0
		10.0	60	1.5
	2300	9.5	61	2.0
		9.5	61	3.7
		8.5	61	3.5
10/13/76	0000	7.5	63	3.7
		7.0	65	4.0
		7.0	66	3.3
	0100	7.0	67	3.7
		6.5	67	4.2
		6.0	67	4.0
	0200	6.0	67	4.5
		5.5	68	5.2
		5.5	68	4.8
	0300	6.0	69	5.2
		5.5	70	4.0
		6.0	70	5.4
	0400	6.5	70	6.6
		6.0	70	8.0
		6.0	71	8.4
	0500	6.0	71	8.5
		6.0	72	6.5
		5.5	72	8.0
	0600	5.5	73	9.4
		5.5	73	8.0
		5.0	73	6.4
	0700	5.0	73	6.0
		4.5	74	7.6
		5.0	74	10.0
	0800	5.5	73	8.0
		6.0	73	8.0
		7.5	73	6.6
	0900	10.0	71	10.0
		11.5	68	10.0
		13.0	66	10.4

APPENDIX A (continued)

	T(°C)	Q(%)	Wind Speed (km/hr)
1000	15.0	62	16.0
	16.0	58	16.0
	17.5	57	18.0
1100	18.0	53	17.0
	20.0	52	16.5
	20.5	50	13.0
1200	21.5	50	11.6
	21.5	48	9.6
	22.5	48	6.0
1300	23.5	46	5.6
	24.5	45	5.0
	25.0	44	4.0
1400	25.0	43	5.3
	24.5	43	6.9
	25.0	42	5.2
1500	26.5	42	6.5
	25.5	42	4.0
	26.0	42	7.0
1600	26.0	41	5.4
	25.5	40	6.4
	25.0	40	8.0
1700	25.0	40	5.2
	25.0	40	5.0
	25.0	40	8.4
1800	24.5	40	8.0
	23.5	40	8.0
	21.5	40	7.0
1900	19.0	42	6.8
	17.0	44	7.0
	16.0	46	7.5
2000	15.0	47	7.4
	14.0	48	7.5
	13.0	49	8.6
2100	13.0	51	8.3
	11.5	53	7.8
	11.5	53	7.5
2200	11.0	55	6.5
	10.0	57	6.0
	10.0	58	10.0
2300	10.5	58	11.4
	10.5	58	11.0
	11.5	58	15.2

APPENDIX A (continued)

		T(°C)	Q(%)	Wind Speed (km/hr)
10/14/76	0000	12.0	58	17.0
		12.0	58	17.0
		12.0	58	20.0
	0100	12.0	58	19.6
		11.5	58	19.0
		12.0	59	20.0
	0200	11.5	57	19.0
		10.5	57	19.0
		11.0	57	19.0
	0300	10.5	57	17.0
		10.0	57	19.0
		10.0	57	19.0
	0400	10.0	57	18.0
		10.0	57	19.0
		10.0	57	17.0
	0500	10.0	57	20.0
		9.5	57	16.0
		9.0		15.0
	0600	8.5	57	13.0
		8.0	59	16.0
		7.5	59	16.0
	0700	7.5	60	15.0
		7.0	61	14.0
		6.0	62	13.0
	0800	6.0	63	12.0
		8.5	65	12.0
		10.0	67	11.6
	0900	11.5	67	12.4
		13.5	67	15.0
		14.0	67	17.0
	1000	16.6	63	18.0
		17.0	62	21.0
		18.5	60	27.0
	1100	20.0	58	25.0
		20.0	56	24.0
		21.5	54	24.0
	1200	22.0	52	24.0
		22.5	51	21.5
		23.5	49	18.0
	1300	24.0	48	17.0
		24.5	47	14.0
		25.0	47	12.0

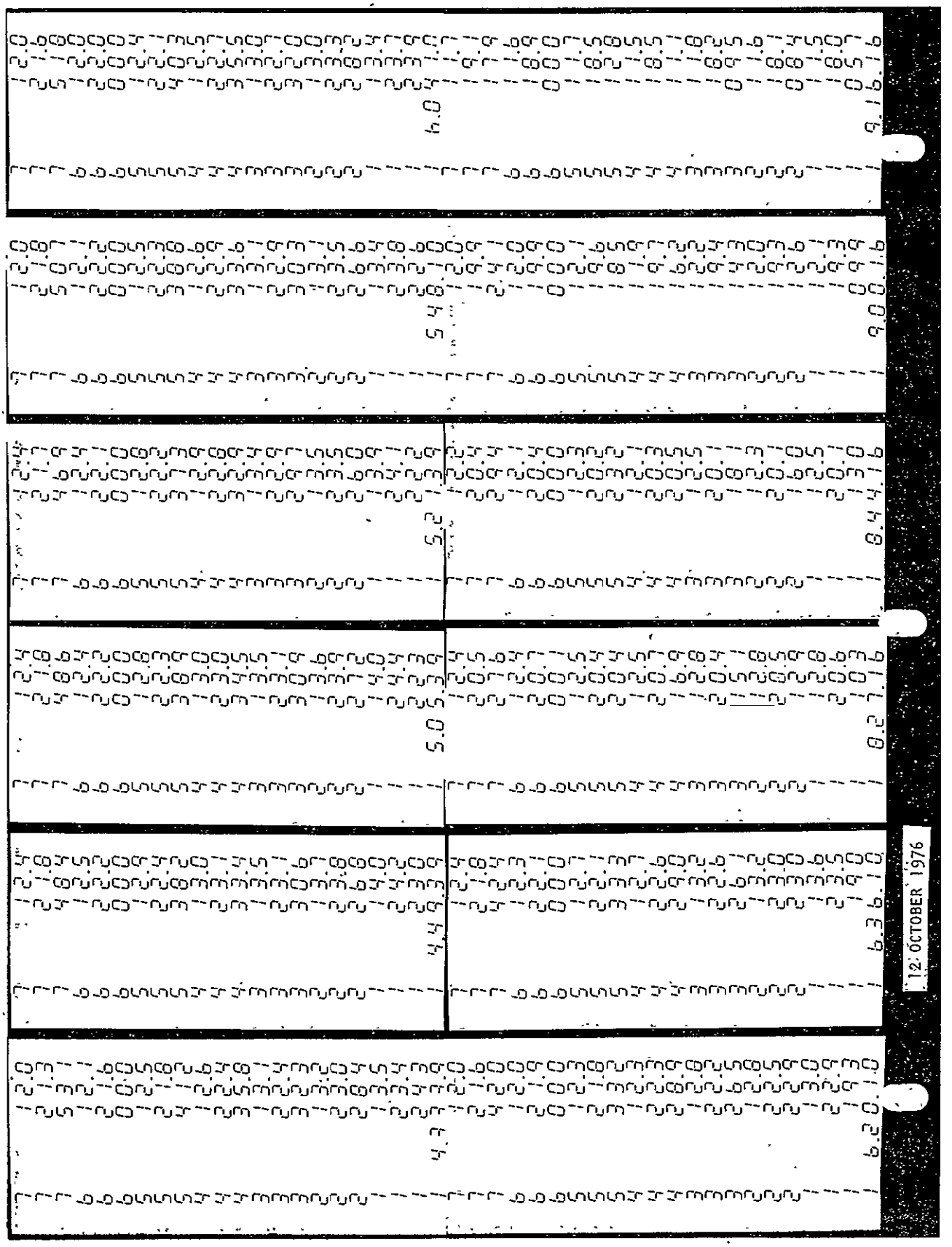
APPENDIX A (continued)

		T(°C)	Q(%)	Wind Speed (km/hr)
	1400	25.5	45	12.0
		26.5	44	11.4
		27.5	43	9.8
	1500	27.5	42	8.0
		28.5	41	10.0
		28.5	40	12.0
10/14/76	1600	28.5	39	12.0

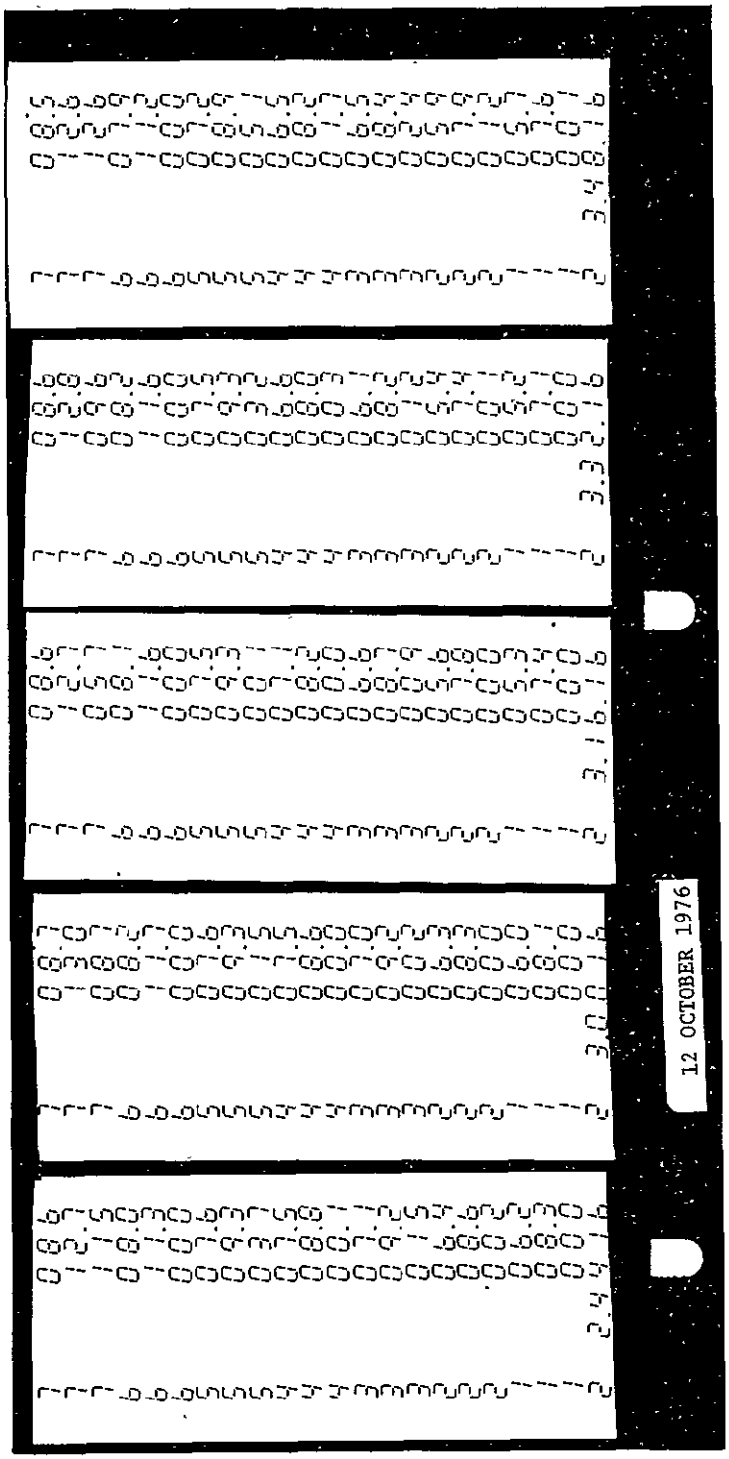
APPENDIX B

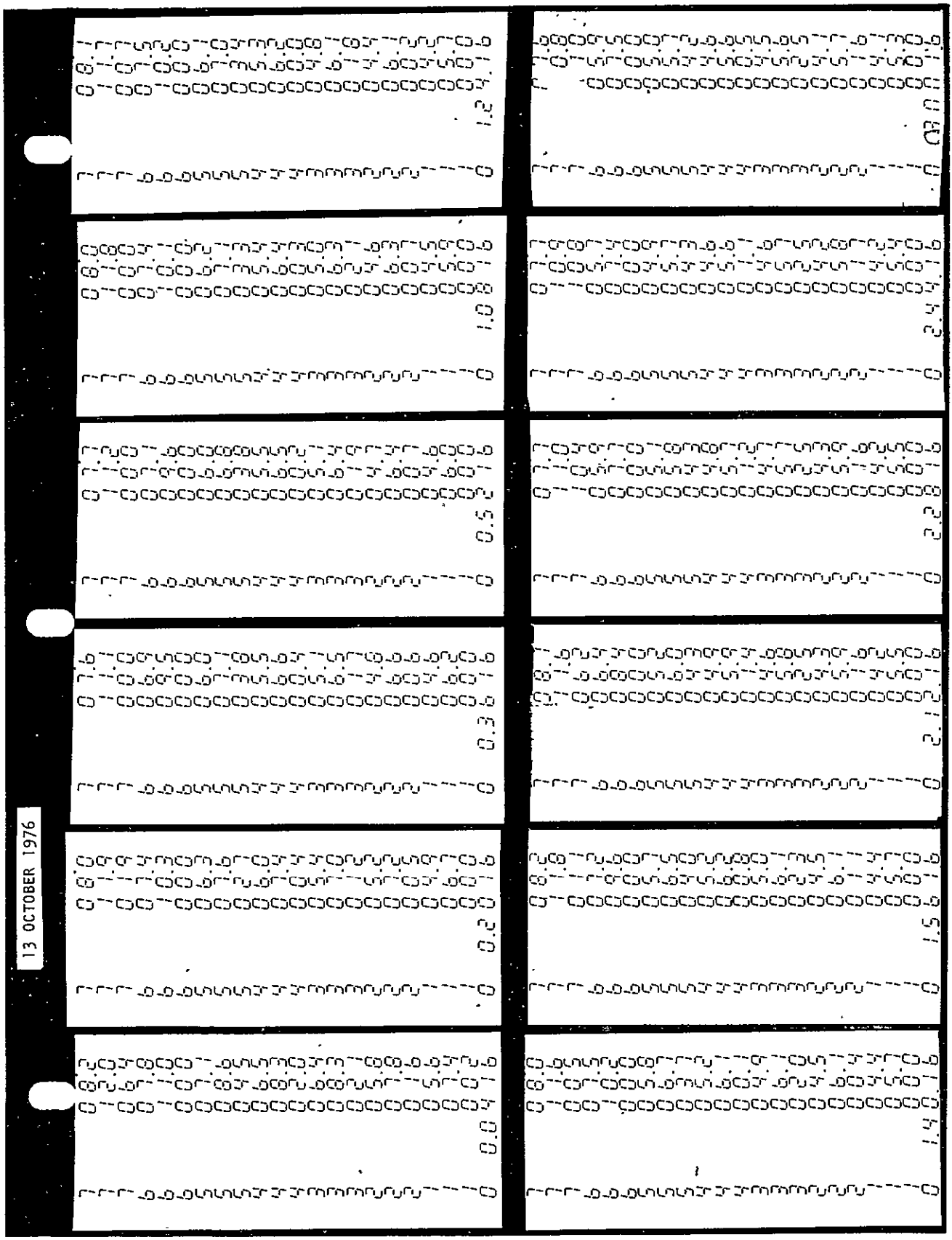
METEOROLOGICAL VARIABLES: SEVEN LEVELS

11-12 OCTOBER 1976



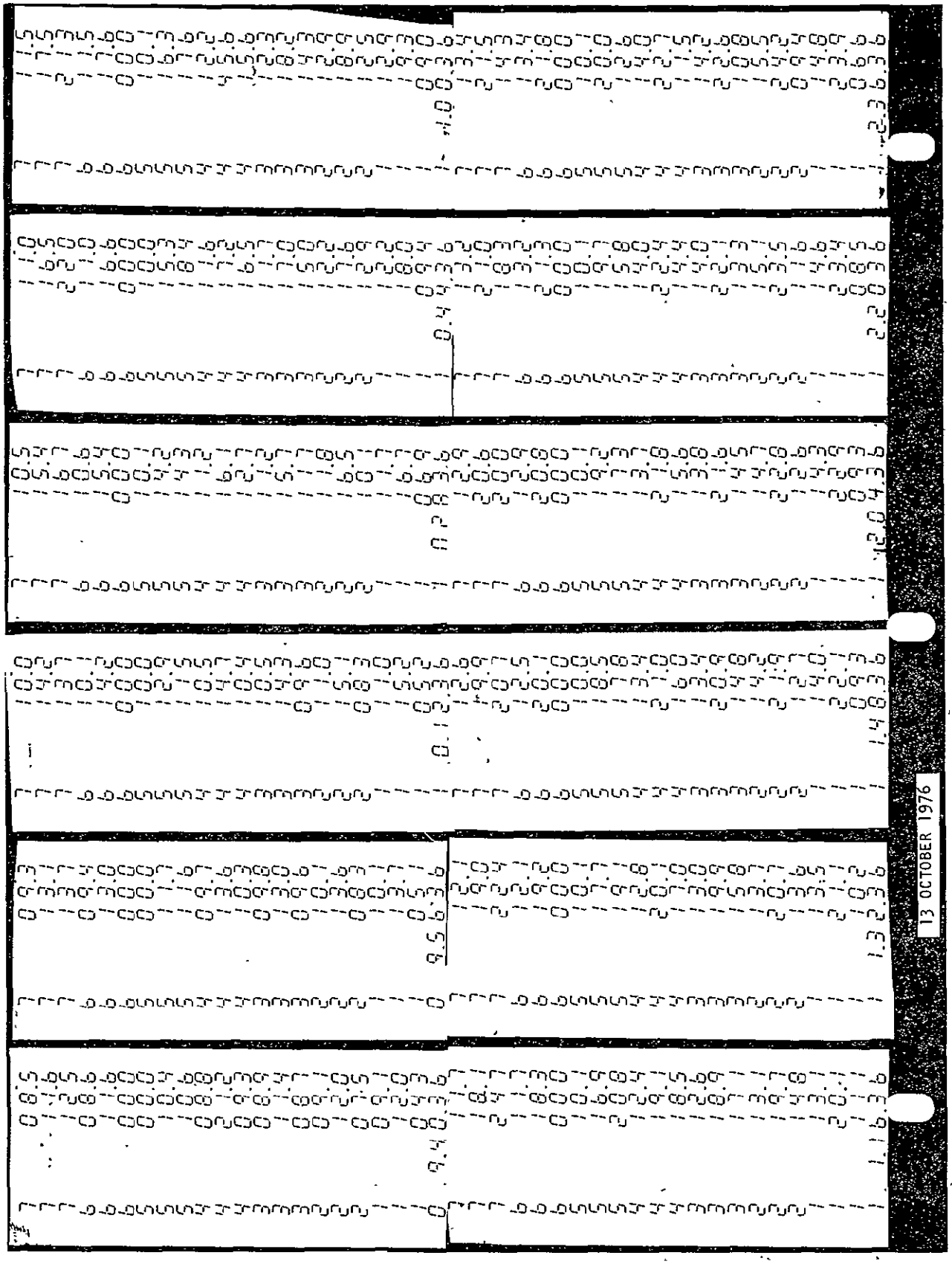
12 OCTOBER 1976

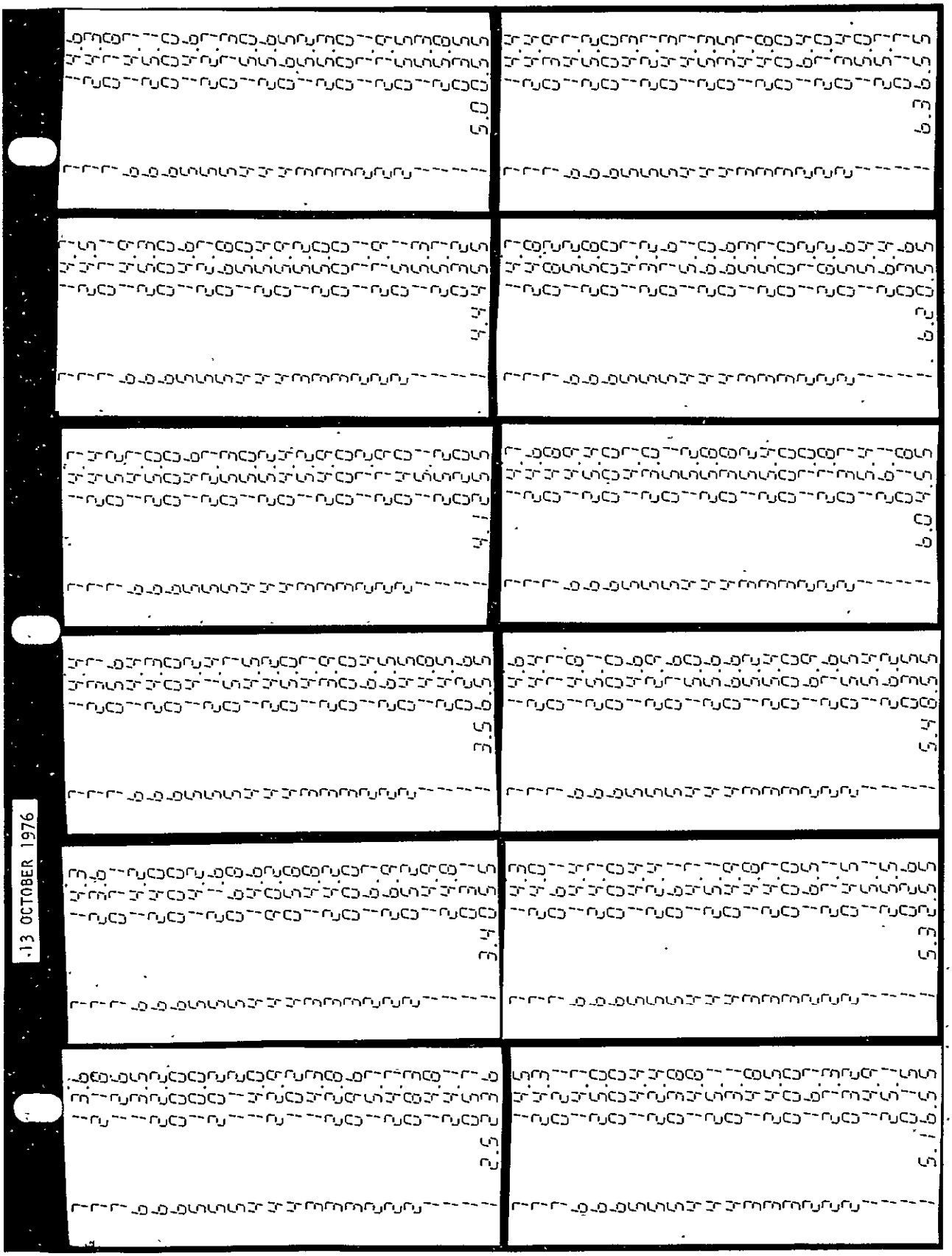

12 OCTOBER 1976

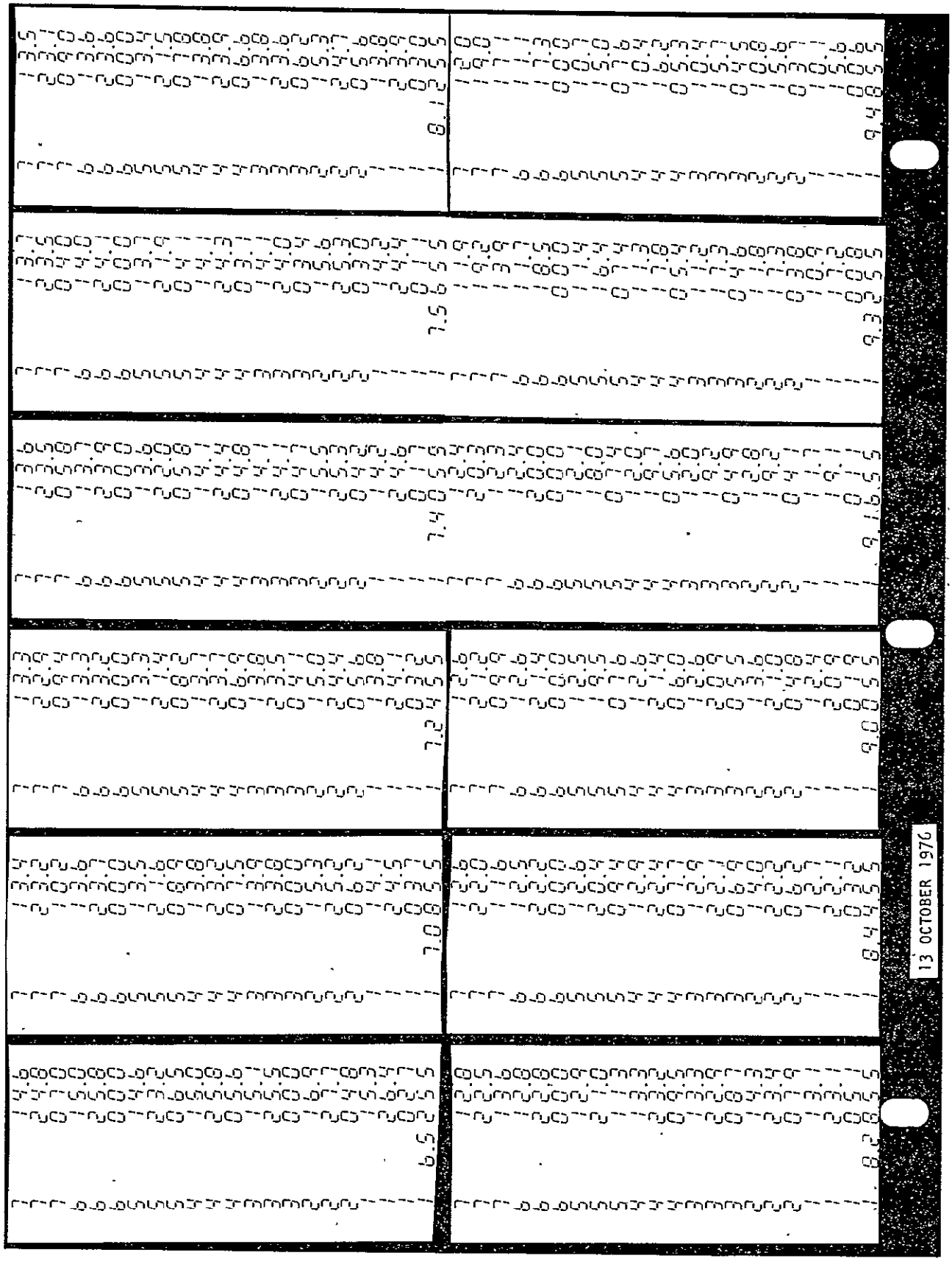

13 OCTOBER 1976

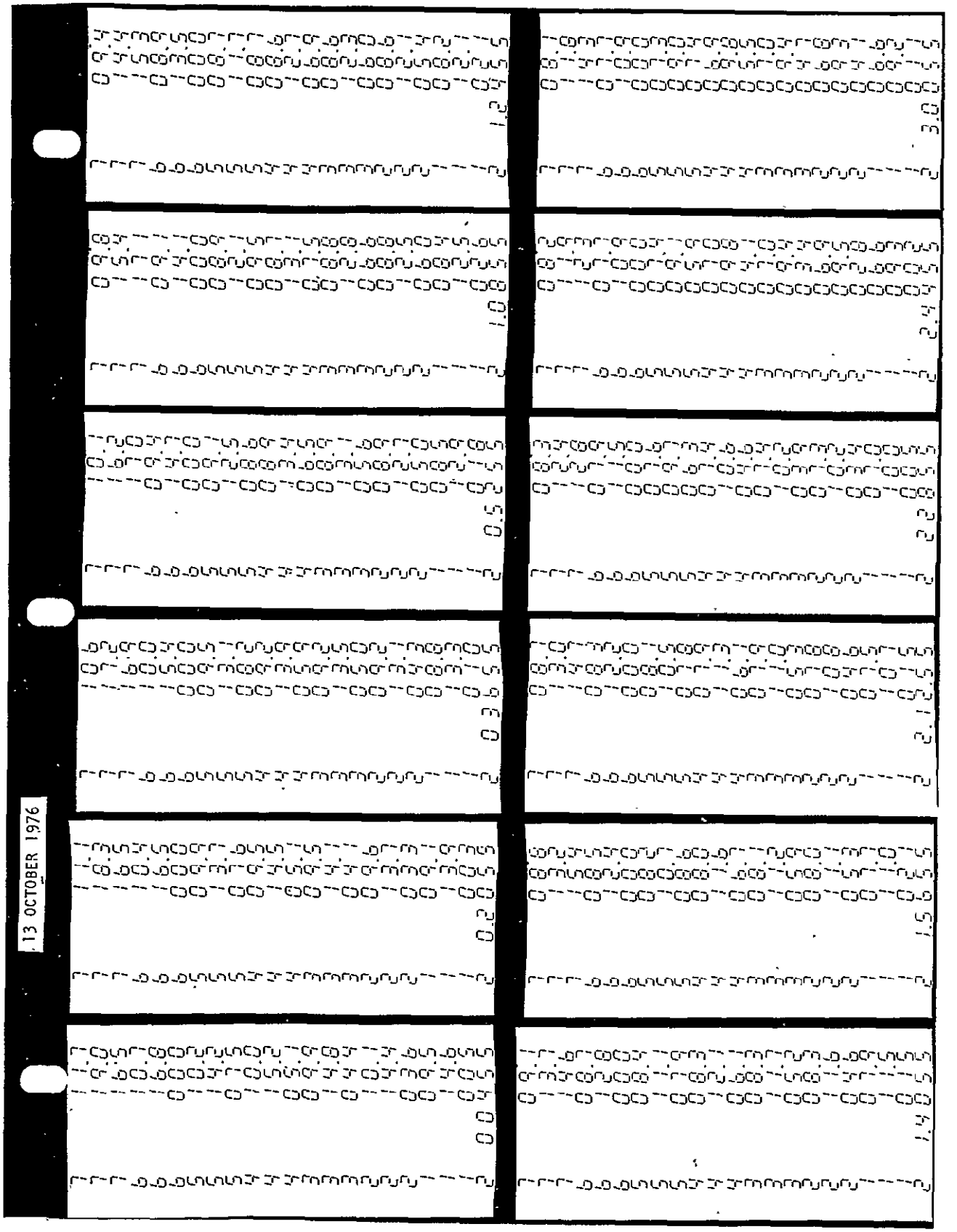
13 OCTOBER 1976

13 OCTOBER 1976

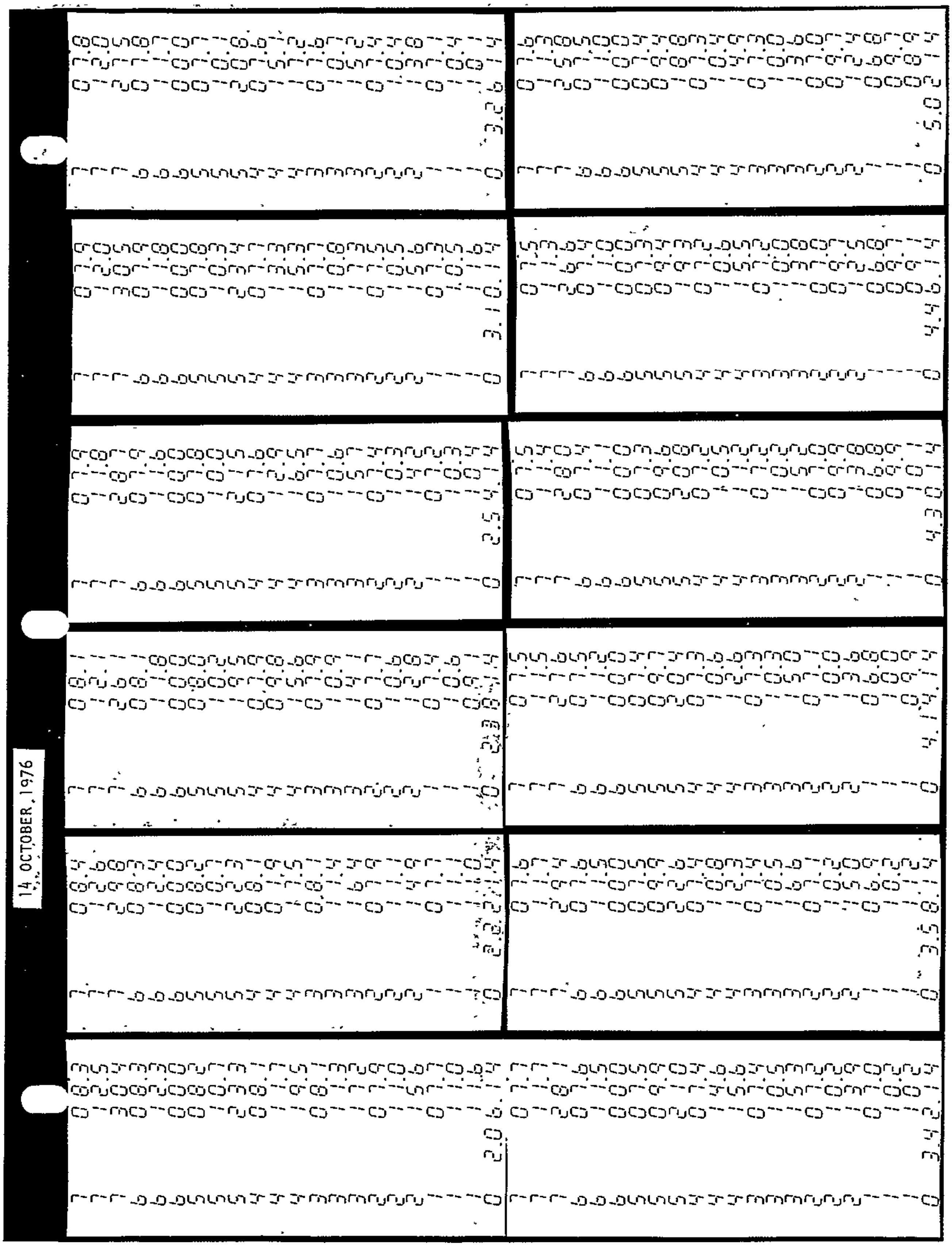

13 OCTOBER 1976


13 OCTOBER 1976

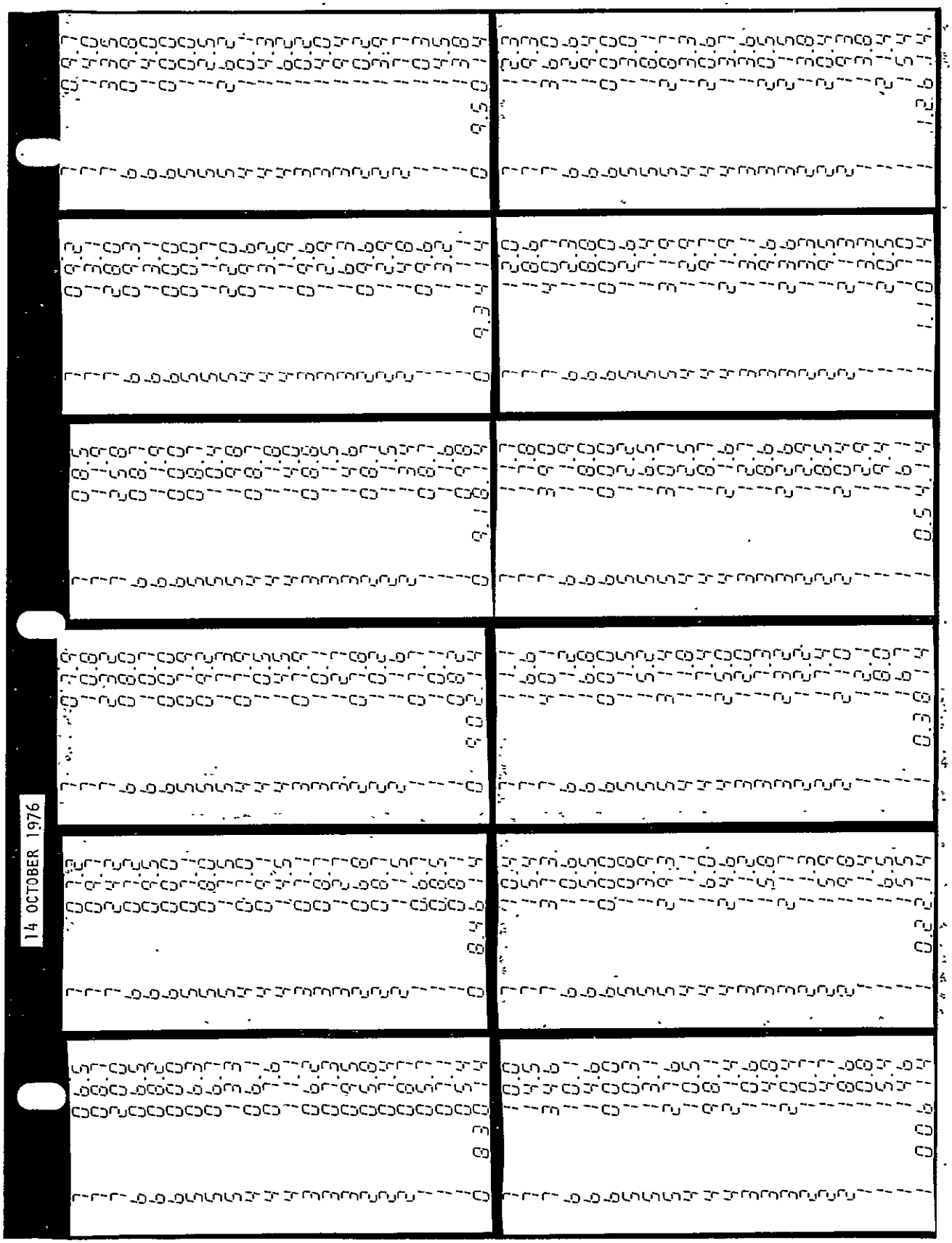


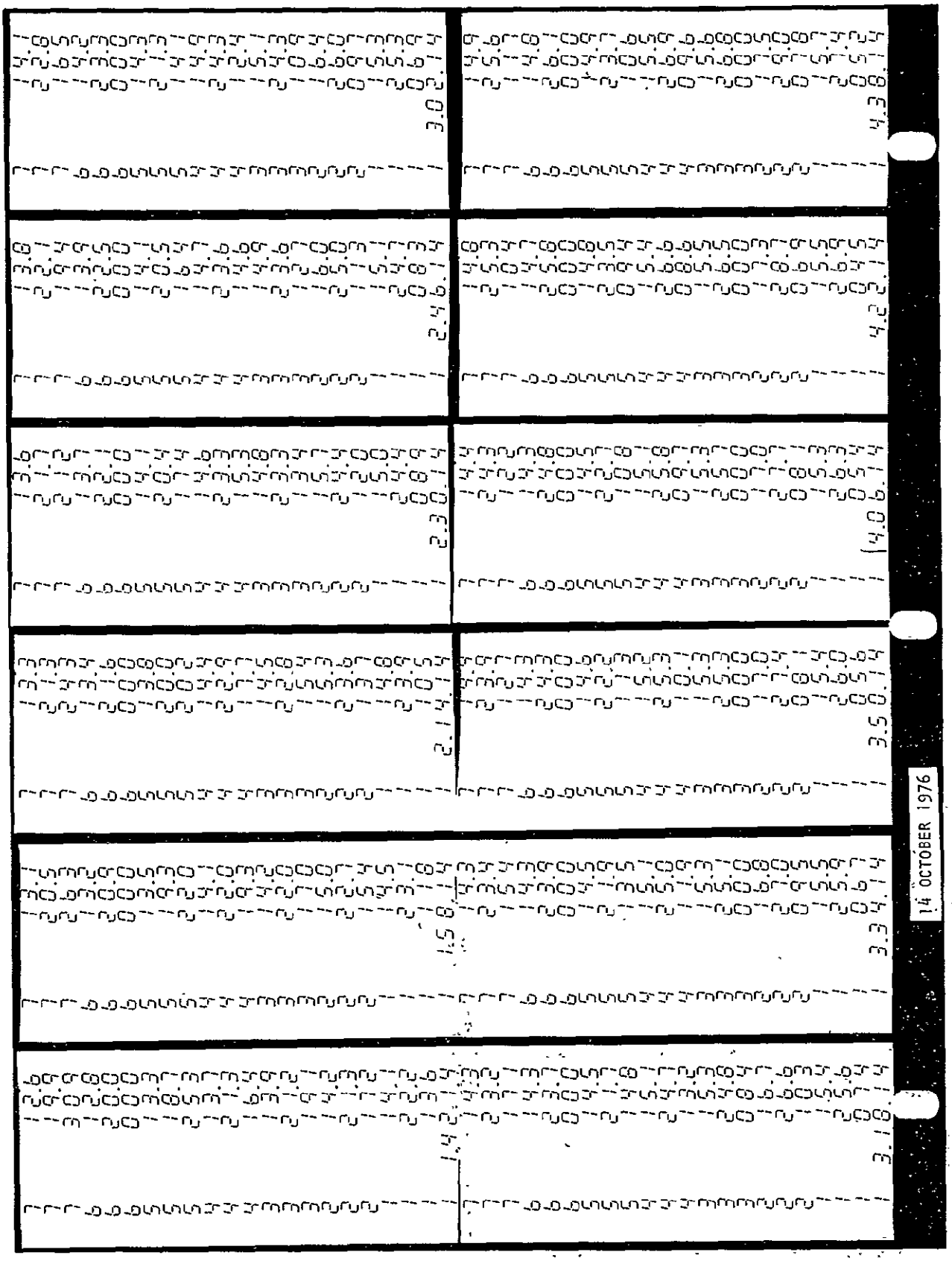


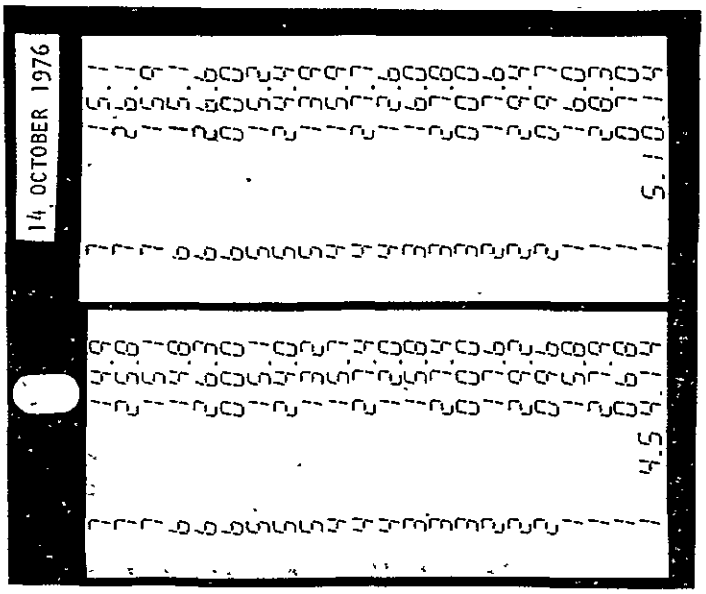
14 OCTOBER 1976


14 OCTOBER, 1976

14 OCTOBER 1976

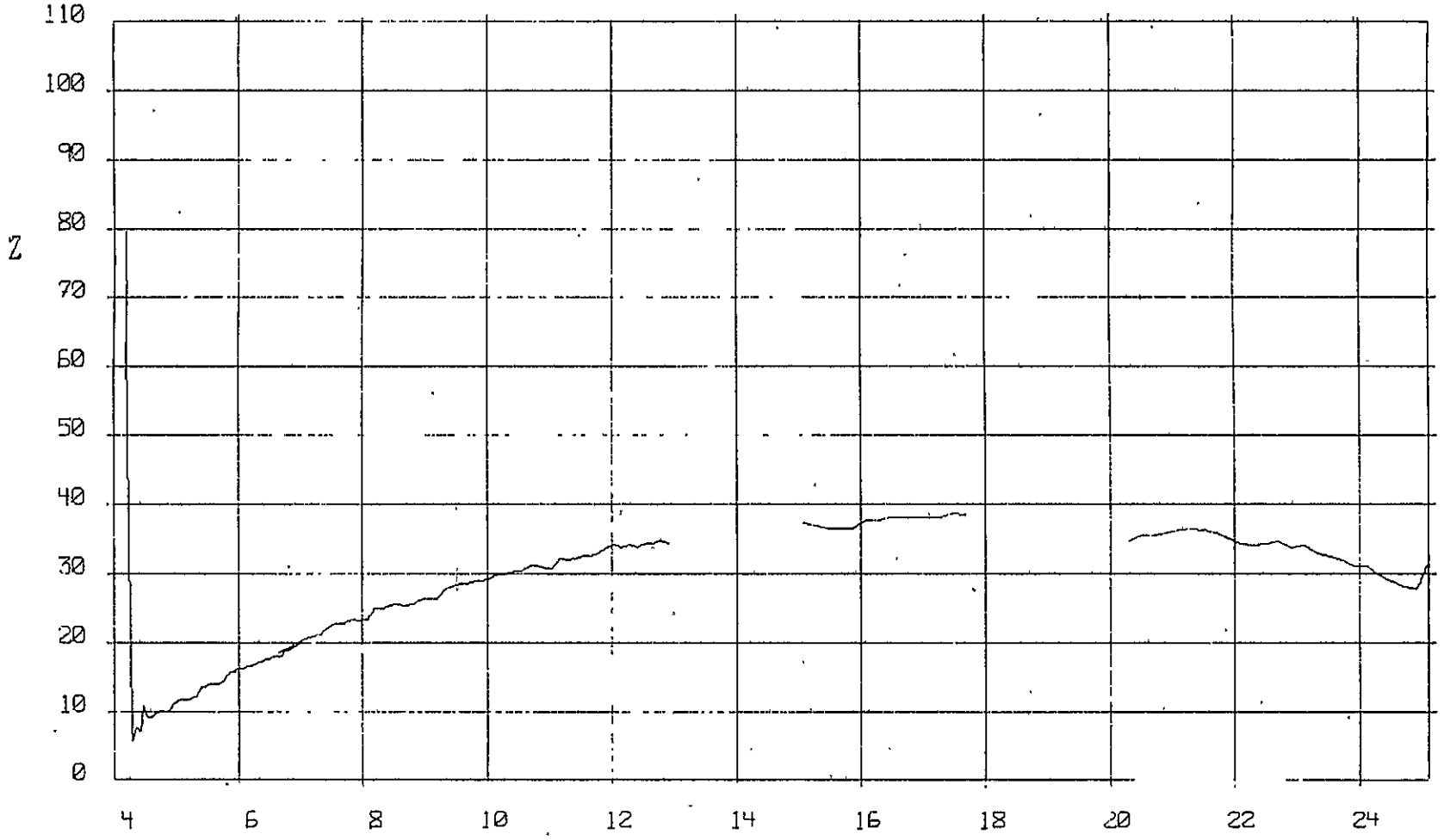



14 OCTOBER 1976


14 OCTOBER 1976

APPENDIX C

SURFACE REFLECTIVITY

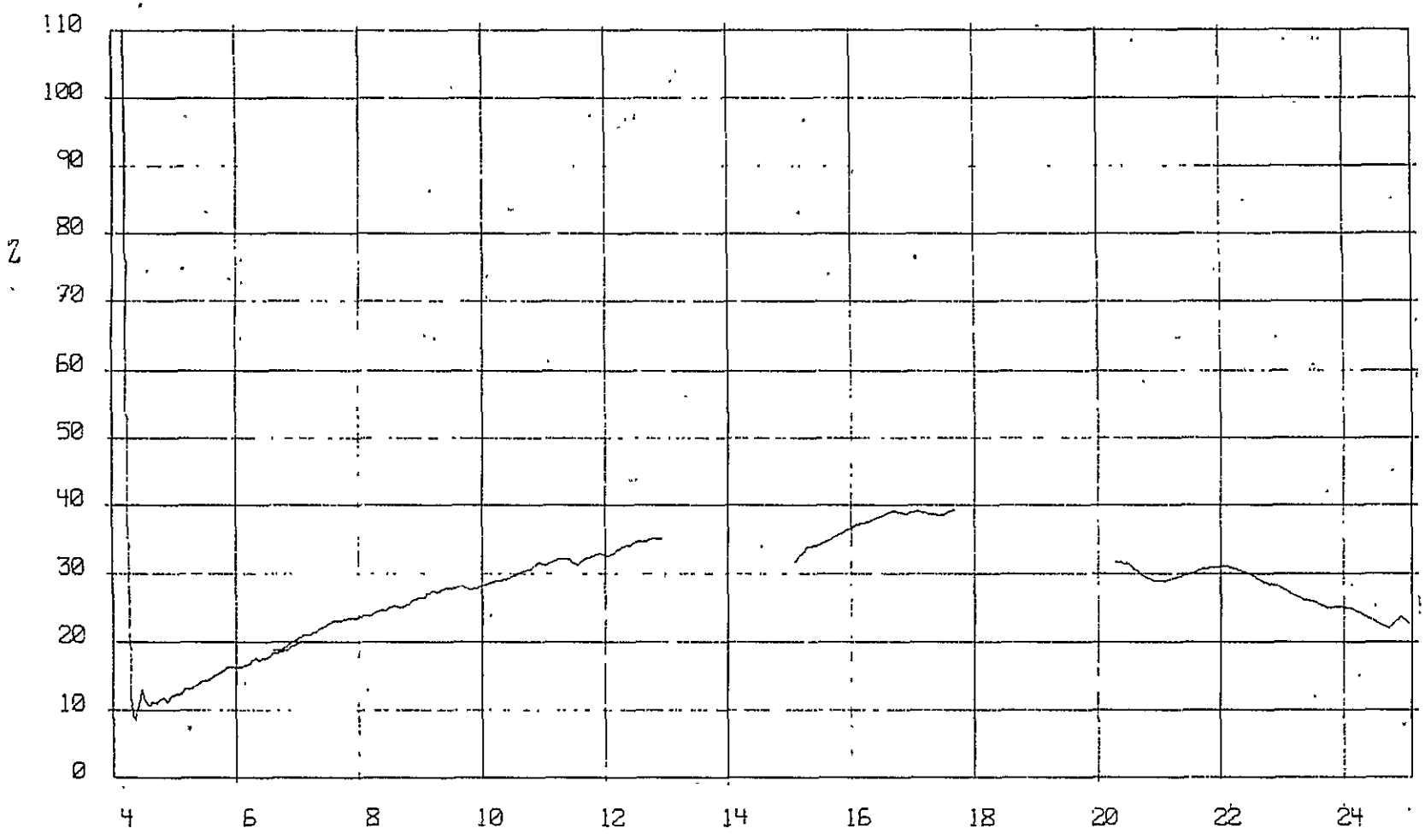


SITE 1

NEWLY PLANTED WHEAT FIELD

SITE 2

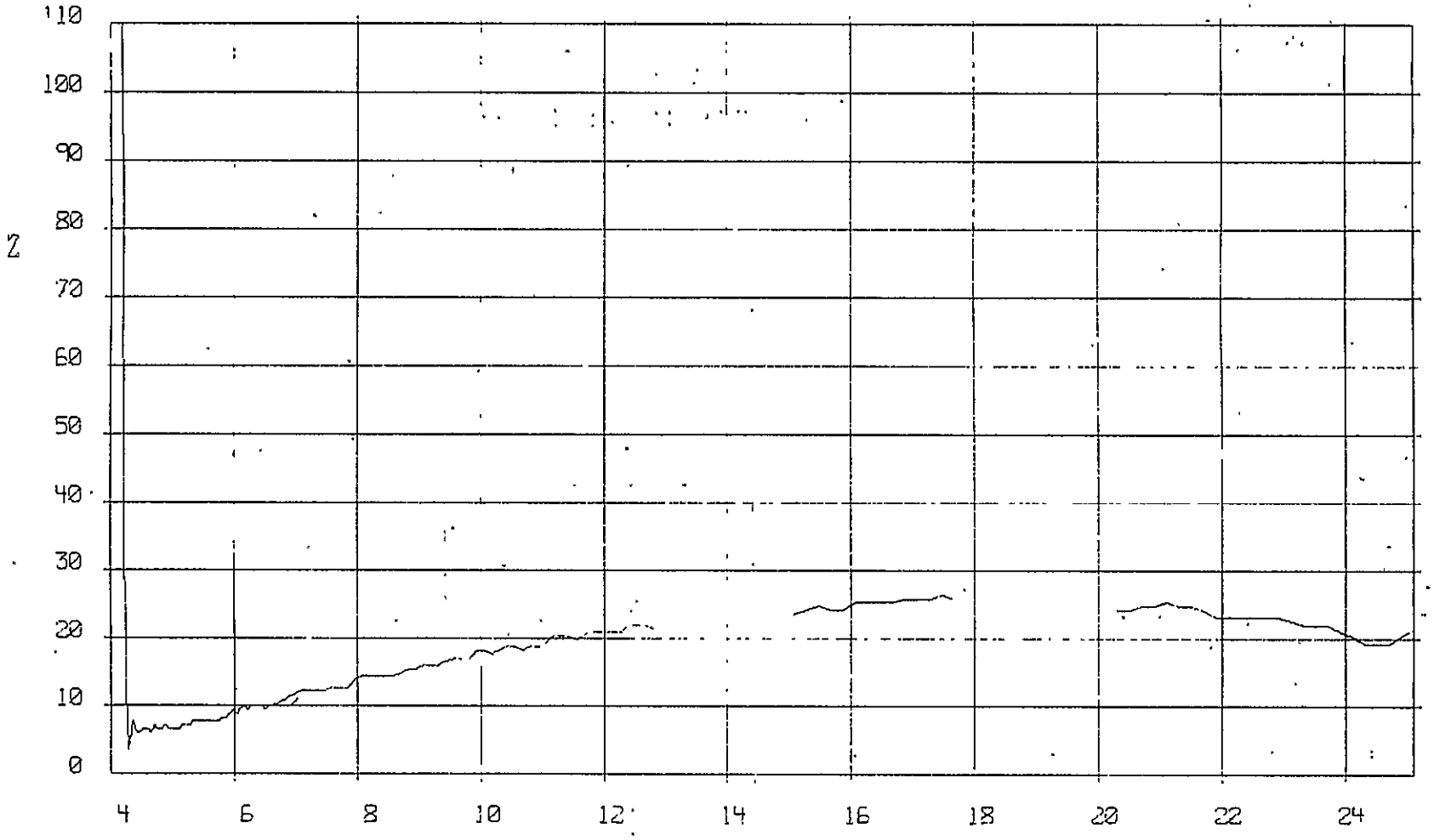
NEWLY PLANTED WHEAT FIELD



SITE 3'
WHEAT STUBBLE FIELD

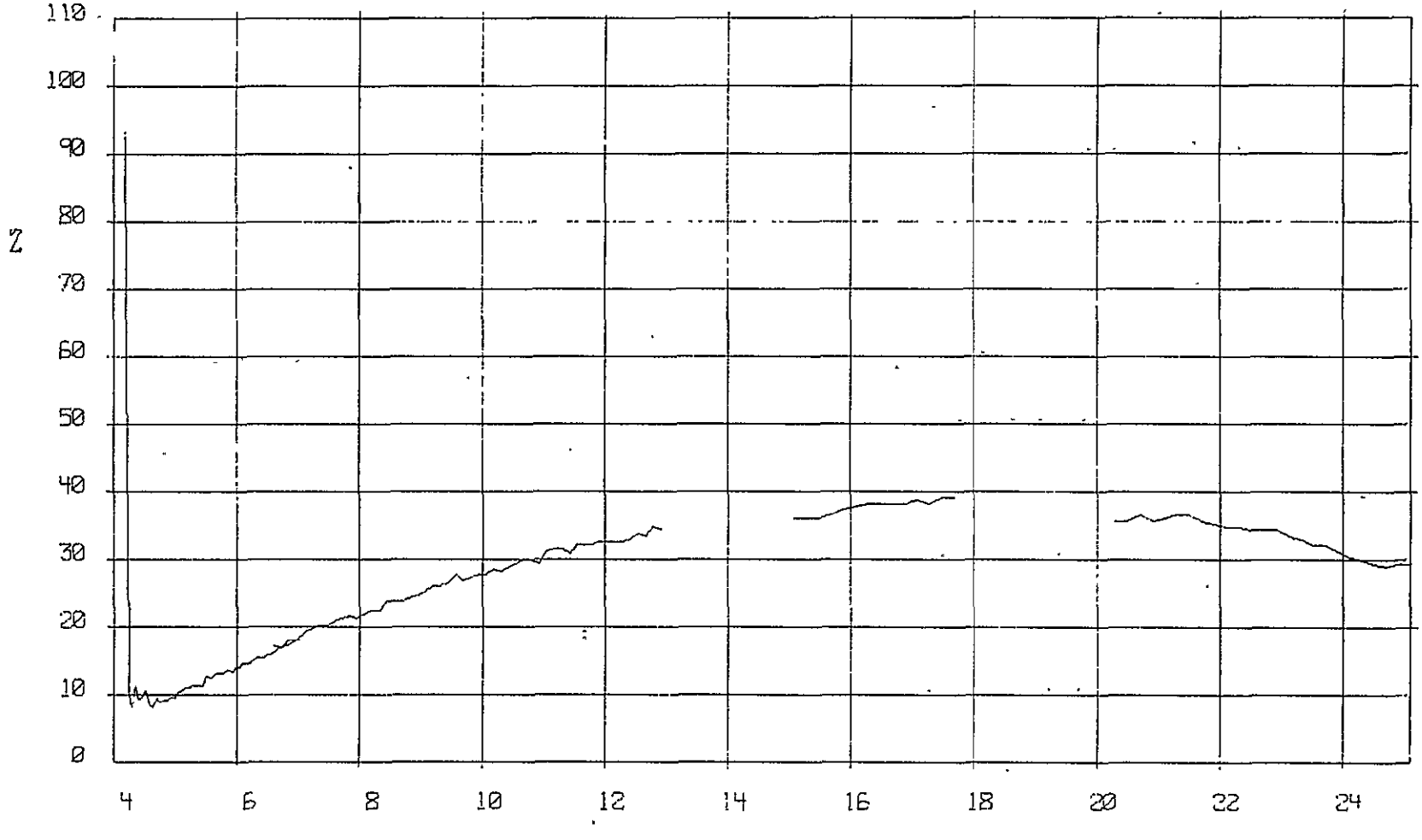
SITE 4A & B

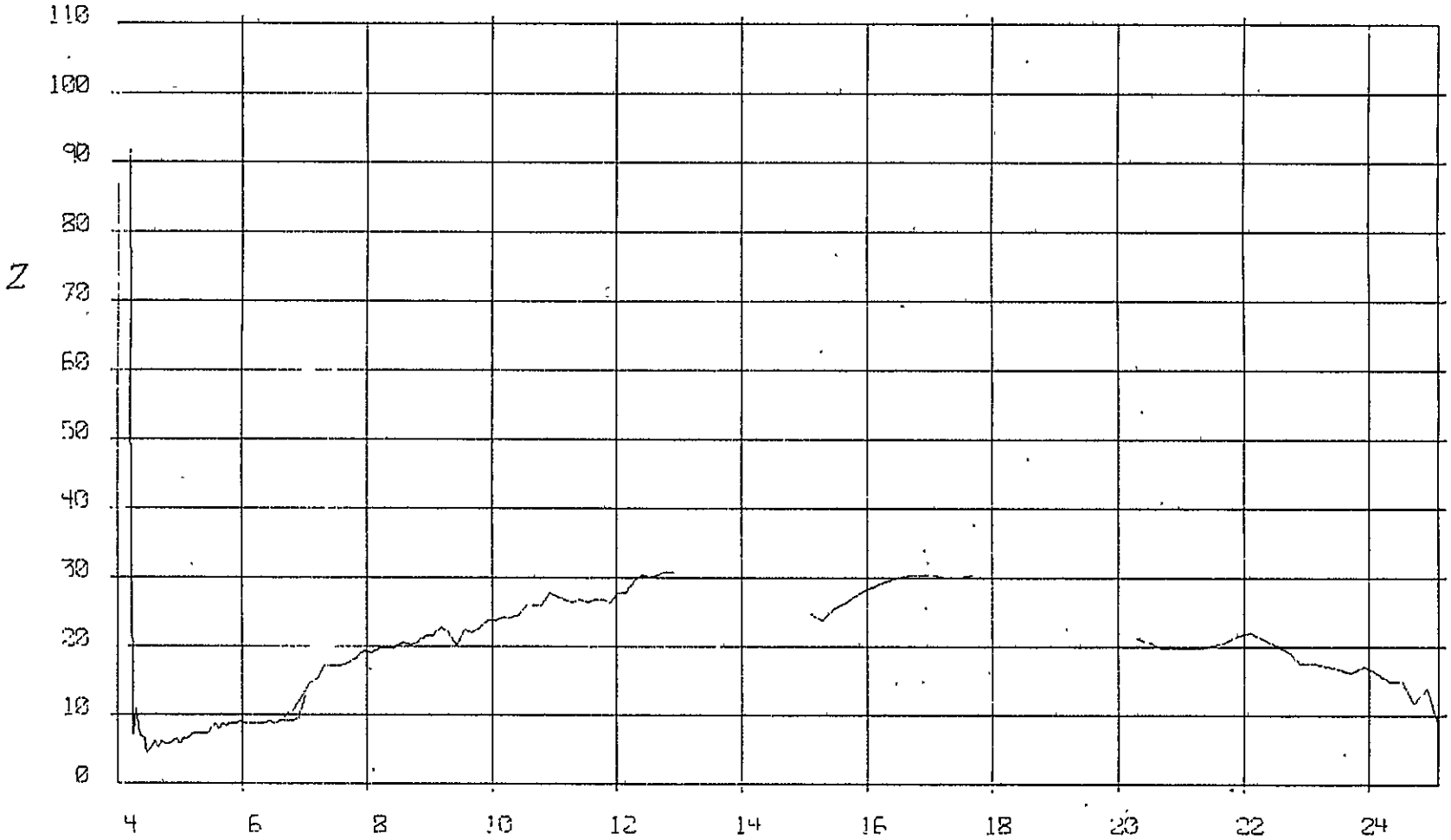
BARE FIELD



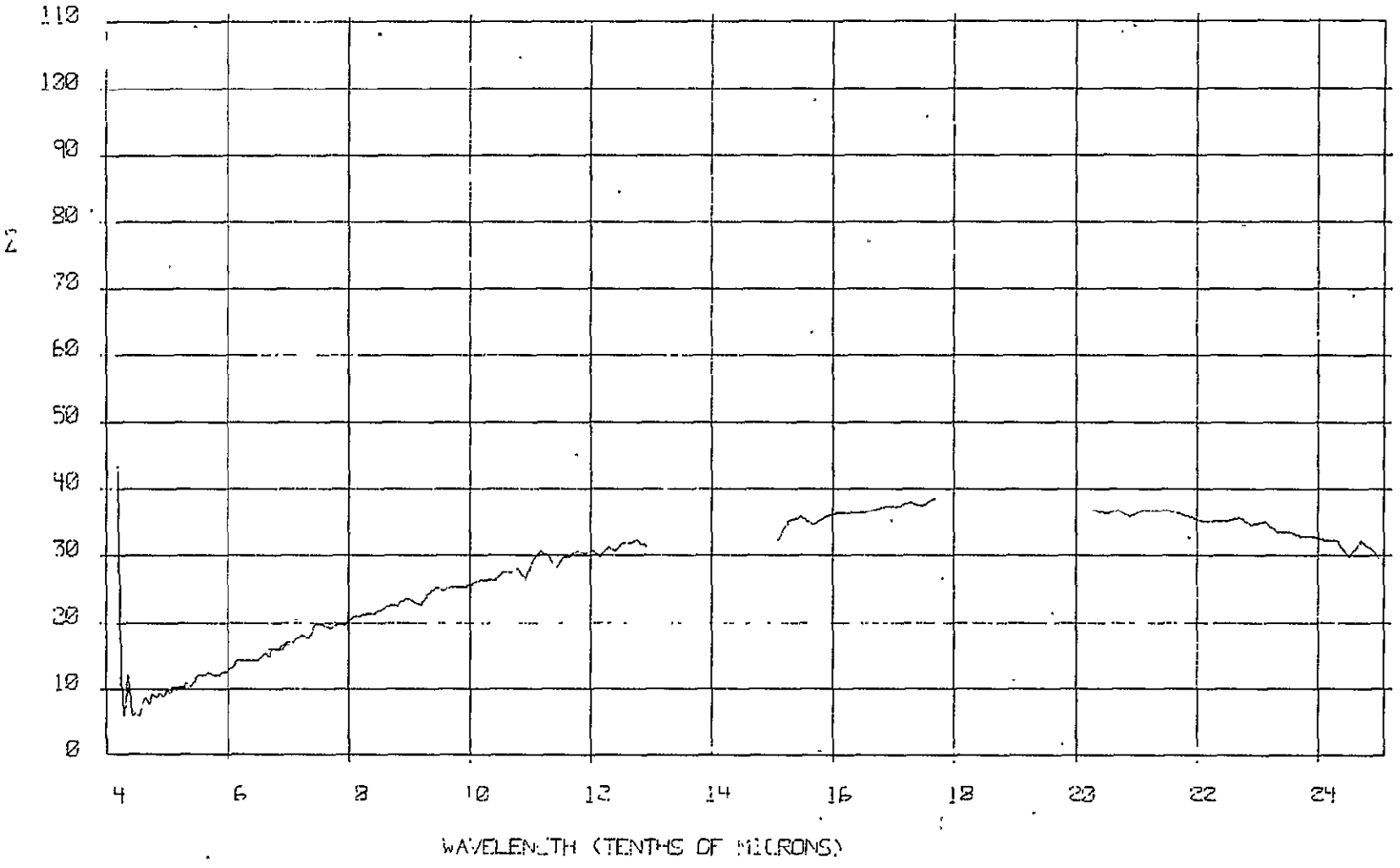
SITE 5

NEWLY PLANTED WHEAT FIELD

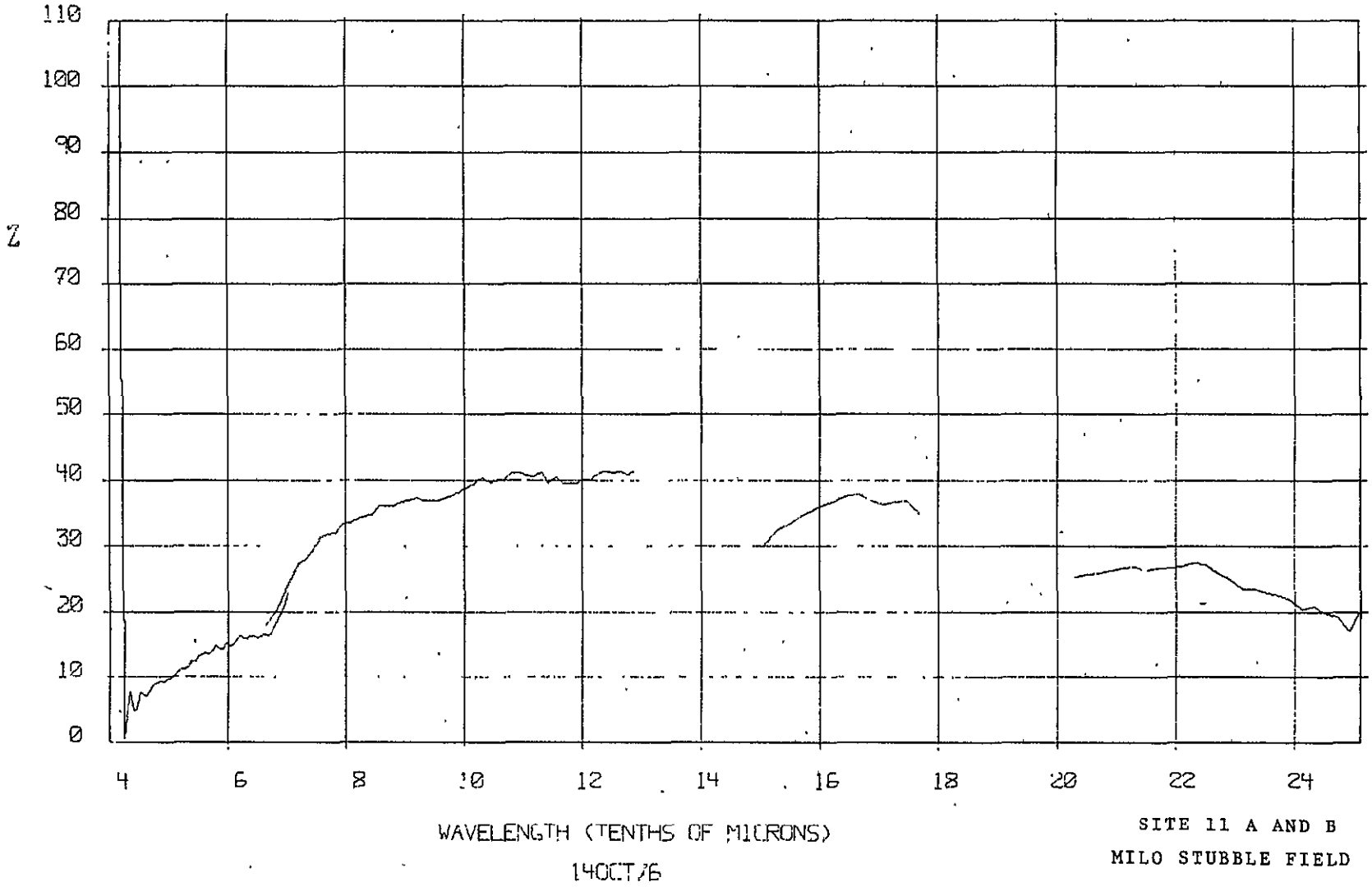

110
100
90
80
70
60
50
40
30
20
10
0
%
4
6
8
10
12
14
16
18
20
22
24
WAVELENGTH (TENTHS OF MICRONS)
140CT76
SITE 6
NEWLY PLANTED WHEAT FIELD



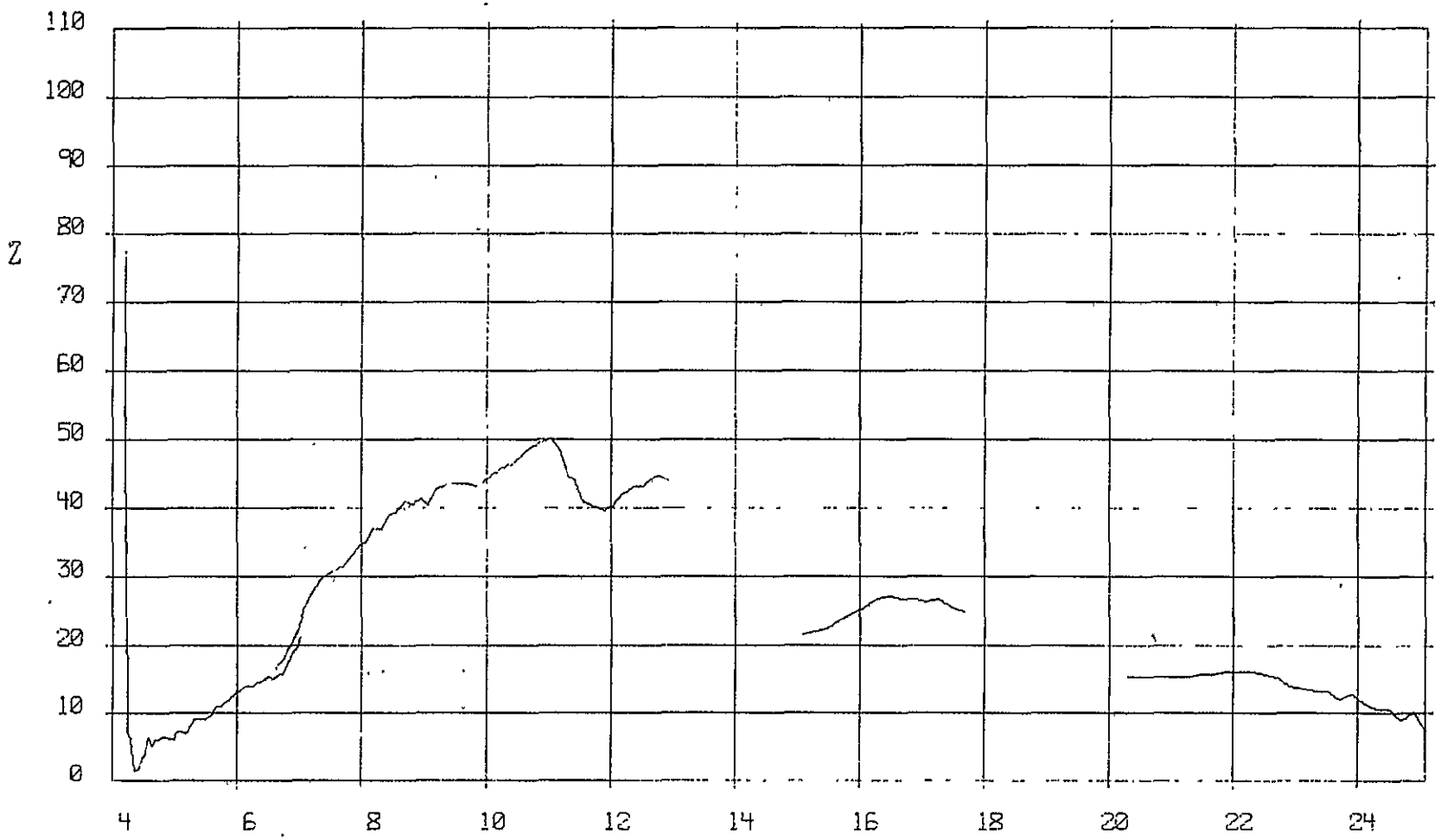
SITE 8A
GRASSY FIELD



SITE 8B
NEWLY PLANTED WHEAT FIELD

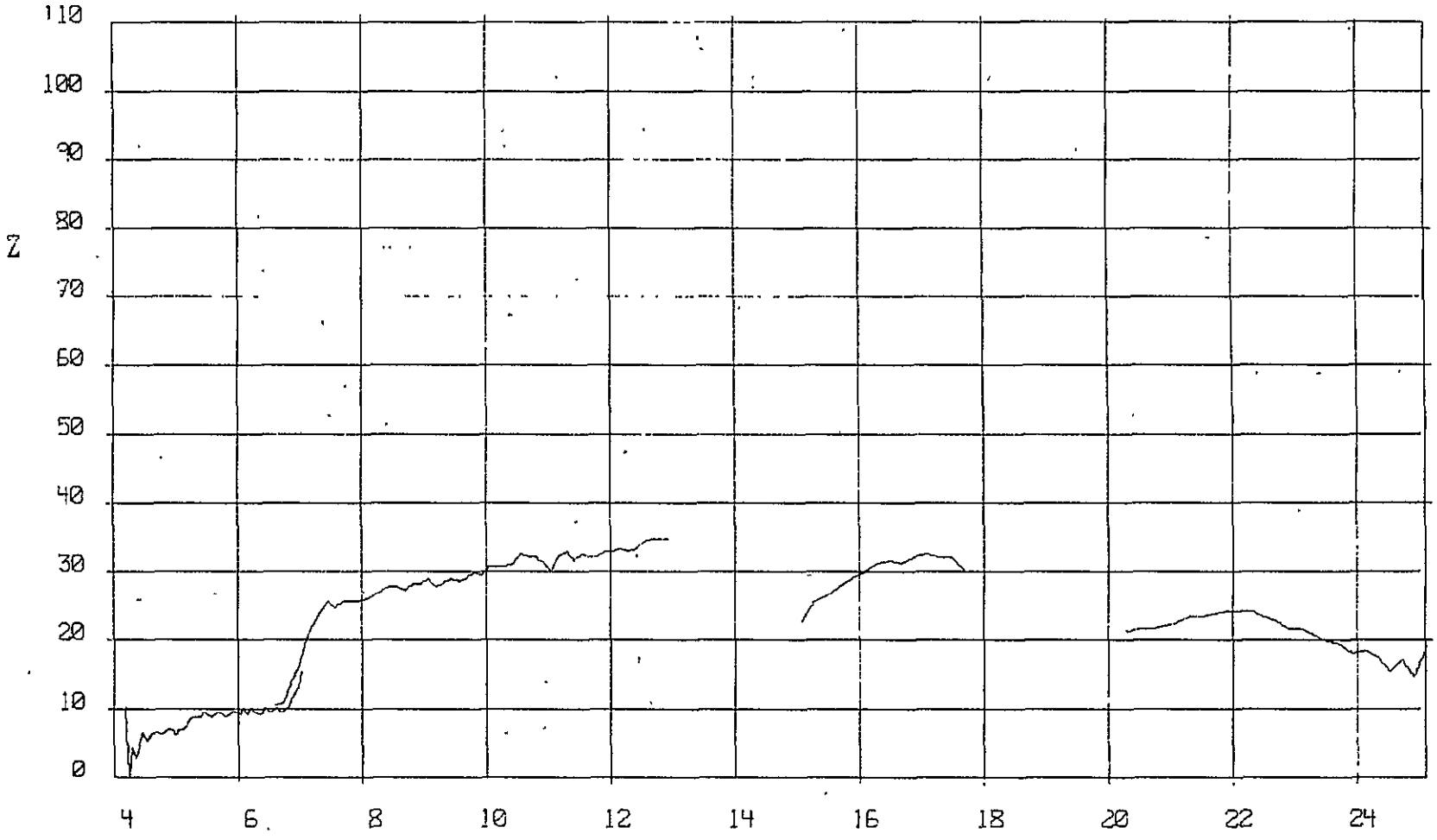


SITE 11 A AND B
MILO STUBBLE FIELD



SITE 12

MATURE MILO FIELD



SITE 13

WHEAT STUBBLE FIELD

APPENDIX D

SURFACE AND SUBSURFACE TEMPERATURES

	SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
10/13/76	1	0652	6.5° ± 0.5°	11.5°	14.3°	15.5°	15.8°
	2	0659	6.5° ± 0.5°				
	3	0655	7.0° ± 1.0°	11.2°	12.3°	14.6°	14.9°
	4A	0645	7.0° ± 0.5°				
	B		7.0° ± 0.2°				
	5	0706	6.5° ± 1.5°	10.0°	13.0°	14.0°	15.0°
	6	0710	7.0° ± 1.0°	9.9°	12.0°	14.0°	15.0°
	7	0720	7.0° ± 1.0°	11.0°	12.9°	14.5°	15.0°
	8	0726	5.0° ± 1.0°	11.0°	13.0°	14.5°	15.1°
	9	0735	7.5° ± 0.5°				
	10	0740	6.0° ± 1.5°	10.5°	12.5°	14.5°	15.0°
	11A	0741	6.5° ± 1.0°				
	B		7.0° ± 0.5°				
	12	0745	7.5° ± 0.5°				
	13	0746	7.5° ± 0.5°				
	14	0749	7.5° ± 0.5°	9.5°	11.5°	14.8°	15.0°
	1	0815	7.5° ± 0.5°	11.2°	14.0°	15.5°	15.8°
	2	0817	8.5° ± 2.0°				
	3	0810	8.2° ± 1.5°	11.0°	12.5°	14.7°	15.3°
	4A	0807	7.5° ± 0.5°				
	B	0808	7.5° ± 0.5°				
	5	0820	8.5° ± 0.5°	10.0°	13.2°	14.9°	15.2°
	6	0823	8.5° ± 0.5°	10.0°	12.5°	14.5°	15.2°
	7	0832	9.2° ± 2.0°	11.3°	13.1°	14.9°	15.2°
	8	0840	9.5° ± 0.5°	10.5°	12.9°	14.7°	15.4°
	9	0849	10.5° ± 0.2°				
	10	0853	10.6° ± 0.5°	10.5°	12.8°	14.9°	15.1°
	11A	0854	12.2° ± 0.1°				
	B	0854	9.0° ± 0.2°				
	12	0858	12.0° ± 0.5°				
	13	0859	11.0° ± 0.6°				
	14	0901	12.1° ± 0.2°	10.1°	11.8°	15.0°	15.2°

APPENDIX D (continued)

SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
1	0917	13.0° ± 1.0°	10.2°	13.9°	15.3°	16.0°
2	0920	13.0° ± 0.5°				
3	0922	13.0° ± 1.2°	11.0°	12.0°	14.8°	15.0°
4A	0906	12.0° ± 1.0°				
B	0914	10.5° ± 0.5°				
5	0924	14.0° ± 1.0°	10.1°	13.0°	14.8°	15.2°
6	0925	14.0° ± 2.0°	10.2°	12.1°	14.2°	15.0°
7	0932	20.0° ± 3.0°	10.3°	13.0°	14.9°	15.2°
8	0938	15.0° ± 3.0°	11.0°	12.9°	14.5°	15.1°
9	0947	15.0° ± 1.0°				
10	0950	17.0° ± 4.0°	11.0°	12.5°	14.5°	15.0°
11A		15.5° ± 0.5°				
B		13.0° ± 1.0°				
12	0956	15.0° ± 1.0°				
13	0957	15.0° ± 2.0°				
14	1000	17.0° ± 1.5°	10.7°	11.9°	14.9°	15.1°
1	1028	21.0° ± 5.0°	16.2°	15.5°	15.0°	15.8°
3	1027	19.0° ± 3.0°	14.0°	13.2°	14.1°	14.8°
4A	1025	19.0° ± 2.0°				
B	1026	18.0° ± 2.0°				
1	1255	36.0° ± 5.0°				
2	1259	35.0° ± 12.0°				
3	1257	33.0° ± 7.0°				
4A	1250	33.0° ± 2.0°				
B	1253	32.0° ± 1.5°				
5	1302	37.5° ± 7.0°	15.4°	13.2°	14.5°	15.2°
6	1305	37.0° ± 10.0°	17.4°	13.5°	14.0°	15.0°
7	1316	38.0° ± 10.0°	16.8°	14.1°	14.7°	15.1°
8	1324	39.0° ± 5.0°	16.2°	13.8°	14.2°	15.2°
9	1338	28.0° ± 5.0°				
10	1342	39.0° ± 10.0°	16.5°	14.0°	14.2°	14.8°
11A		28.5° ± 2.0°				
B		36.0° ± 5.0°				
12	1344	27.0° ± 2.0°				
13	1345	30.0° ± 6.0°				
14	1350	37.0° ± 10.0°	22.0°	15.8°	14.8°	15.0°

APPENDIX D (continued)

SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
1	1421	40.0° ± 3.0°	19.0°	14.9°	15.0°	15.7°
2	1424	40.0° ± 15.0°				
3	1422	37.0° ± 7.0°	16.9°	14.9°	14.0°	14.8°
4A	1417	36.0° ± 4.0°				
B	1419	34.0° ± 3.0°				
5	1430	42.5° ± 10.0°	18.5°	14.1°	14.4°	15.2°
6	1434	42.0° ± 15.0°	20.0°	15.0°	14.1°	15.1°
7	1442	38.0° ± 8.0°	19.2°	15.2°	14.8°	15.0°
8	1449	40.0° ± 3.0°	18.6°	15.0°	14.5°	15.0°
9	1456	31.0° ± 10.0°				
10	1500	40.0° ± 15.0°	18.0°	15.4°	14.3°	15.0°
11A	1502	28.0° ± 0.2°				
B	1503	37.3° ± 7.0°				
12	1509	26.5° ± 1.5°				
13	1510	36.0° ± 10.0°				
14	1514	37.5° ± 8.0°	23.8°	18.8°	14.9°	15.0°
1	1530	37.0° ± 2.0°	20.3°	15.4°	14.9°	15.4°
2	1535	30.0° ± 15.0°				
3	1531	32.0° ± 8.0°	18.1°	15.8°	13.9°	14.2°
4A	1527	33.0° ± 2.0°				
B	1529	34.0° ± 2.0°				
5	1537	37.0° ± 3.0°	19.6°	14.7°	14.2°	15.0°
6	1540	40.0° ± 5.0°	20.5°	15.8°	14.0°	14.8°
7	1553	38.0° ± 2.0°	19.9°	16.0°	14.8°	15.0°
8	1604	37.0° ± 2.0°	19.7°	15.9°	14.8°	15.0°
9	1610	30.0° ± 2.0°				
10	1614	35.0° ± 2.0°	20.1°	16.5°	14.5°	15.0°
11A	1615	28.0° ± 1.0°				
B	1616	23.5° ± 0.5°				
12	1620	24.0° ± 2.0°				
13	1621	31.0° ± 5.0°				
14	1625	31.0° ± 4.0°	23.5°	19.6°	14.9°	15.0°

APPENDIX D (continued)

SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
1	1640	30.0° ± 5.0°	21.0°	16.1°	15.0°	15.1°
2	1641	27.0° ± 2.0°	19.5°	17.0°	14.2°	14.5°
3	1644	27.0° ± 2.5°				
4A	1637	29.0° ± 2.0°				
B	1639	27.0° ± 3.0°				
5	1647	33.0° ± 7.0°	20.1°	15.1°	14.5°	15.0°
6	1649	32.0° ± 6.0°	21.2°	16.9°	14.6°	14.9°
7	1657	30.0° ± 5.0°	20.0°	16.8°	14.8°	14.9°
8	1700	28.0° ± 4.0°	19.9°	16.3°	14.8°	14.9°
9	1711	25.0° ± 1.0°				
10	1714	30.0° ± 1.0°	20.1°	17.0°	14.5°	14.9°
11A	1715	25.0° ± 2.0°				
B	1715	21.5° ± 1.0°				
12	1718	23.0° ± 1.0°				
13	1720	22.0° ± 2.0°				
14	1724	30.0° ± 5.0°	22.8°	19.7°	15.0°	15.0°
1	2036	13.2° ± 0.7°	18.0°	17.1°	15.5°	15.8°
2	2040	13.5° ± 0.7°				
3	2037	13.5° ± 1.0°	16.9°	17.0°	15.0°	15.0°
4A	2032	12.5° ± 1.0°				
B	2034	12.5° ± 0.5°				
5	2048	13.0° ± 1.0°	16.8°	16.1°	15.1°	15.0°
6	2051	13.0° ± 0.5°	16.2°	17.0°	15.5°	15.1°
7	2105	12.0° ± 1.0°	16.2°	17.5°	15.2°	15.2°
8	2115	11.0° ± 1.0°	16.8°	17.2°	16.0°	15.2°
9	2122	11.5° ± 1.5°				
10	2126	12.5° ± 0.5°	16.5°	17.2°	15.3°	14.9°
11A	2127	14.0° ± 0.2°				
B	2128	13.0° ± 0.5°				
12	2136	13.7° ± 0.2°				
13		12.5° ± 0.5°				
14	2142	12.5° ± 0.5°	16.0°	17.3°	16.0°	15.0°

APPENDIX D (continued)

	SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
	1	2349	11.0° ± 0.5°	15.0°	16.5°	16.0°	15.8°
	2	2357	12.0° ± 0.3°				
	3	2353	11.3° ± 0.8°	14.5°	15.3°	15.5°	15.0°
	4A	2346	9.7° ± 0.5°				
	B	2347	9.6° ± 0.2°				
10/14/76	5	0002	11.7° ± 0.3°	14.2°	16.0°	15.5°	15.5°
	6	0005	11.0° ± 0.5°	14.0°	15.8°	16.0°	15.0°
	7	0016	11.0° ± 1.0°	14.9°	16.0°	16.0°	15.9°
	8	0025	10.6° ± 0.5°	15.0°	16.5°	16.2°	16.0°
	9	0033	11.5° ± 0.5°				
	10	0036	11.5° ± 0.5°	15.0°	16.0°	16.0°	15.7°
	11A		14.1° ± 0.1°				
	B	0038	11.2° ± 0.1°				
	12	0041	14.0° ± 0.3°				
	13	0042	11.5° ± 1.5°				
	14	0050	11.3° ± 0.4°	14.2°	15.5°	16.3°	15.9°
	1	0423	10.5° ± 0.2°	13.5°	15.6°	15.8°	15.7°
	2	0426	10.8° ± 0.1°				
	3	0425	10.5° ± 0.2°	13.0°	14.0°	15.1°	15.2°
	4A	0420	8.0° ± 0.2°				
	B	0421	9.0° ± 0.1°				
	5	0429	11.2° ± 0.1°	12.5°	14.9°	15.4°	15.5°
	6	0431	10.5° ± 0.3°	12.3°	14.2°	15.1°	15.2°
	7	0443	9.8° ± 0.2°	13.1°	14.8°	15.5°	15.5°
	8	0452	10.0° ± 0.1°	13.2°	15.0°	15.6°	15.6°
	9	0459	10.6° ± 0.1°				
	10	0502	10.6° ± 0.4°	13.4°	14.9°	15.7°	15.4°
	11A	0503	13.0° ± 0.2°				
	B	0504	11.0° ± 0.1°				
	12	0507	12.8° ± 0.2°				
	13	0508	11.2° ± 0.3°				
	14	0512	10.3° ± 0.2°	12.2°	13.9°	15.8°	15.8°

APPENDIX D (continued)

SITE	TIME	SURFACE (°C)	2" (°C)	5" (°C)	10" (°C)	15" (°C)
1	0801	8.5° ± 0.2°	12.8°	15.0°	16.0°	16.0°
2	0802	9.0° ± 0.1°	12.3°	13.5°	15.0°	15.1°
3	0803	9.0° ± 0.5°				
4A	0800	7.0° ± 0.5°				
B	0801	7.0° ± 0.2°				
5	0806	10.0° ± 0.1°	11.6°	14.1°	15.0°	15.2°
6	0809	9.7° ± 0.2°	11.3°	13.7°	15.0°	15.1°
7	0817	9.0° ± 0.5°	12.5°	14.0°	15.1°	15.2°
8	0824	10.0° ± 0.5°	12.6°	14.1°	15.1°	15.7°
9	0830	10.5° ± 0.5°				
10	0834	10.5° ± 0.2°	12.2°	14.0°	15.0°	15.0°
11A	0835	13.0° ± 0.2°				
B		11.0° ± 0.4°				
12	0839	13.0° ± 0.2°				
13		11.0° ± 1.0°				
14	0843	11.5° ± 0.5°	11.1°	13.0°	15.1°	15.3°
1	0853	12.0° ± 1.5°	12.5°	15.0°	15.6°	16.2°
2	0856	11.5° ± 1.5°				
3	0854	13.0° ± 1.5°	12.0°	14.1°	15.0°	15.2°
4A	0850	11.0° ± 1.5°				
B	0852	10.5° ± 0.5°				
5	0859	13.5° ± 0.5°	11.6°	14.2°	15.1°	15.6°
6	0901	14.0° ± 2.0°	11.8°	13.2°	15.0°	15.2°
7	0908	13.0° ± 3.0°	12.5°	14.0°	15.2°	15.8°
8	0915	14.5° ± 2.5°	13.0°	14.1°	15.5°	15.9°
9	0922	14.0° ± 1.0°				
10	0925	17.0° ± 4.0°	12.8°	14.1°	15.1°	15.6°
11A		15.5° ± 0.5°				
B		12.5° ± 0.5°				
12	0930	16.0° ± 1.5°				
13		14.5° ± 2.5°				
14	0933	16.5° ± 1.5°	12.2°	13.0°	15.2°	16.0°

APPENDIX E

FURROW ORIENTATION EFFECTS ON SURFACE AND SUBSURFACE TEMPERATURES

	LOCATION	TIME	SURFACE	2" (°C)
10/13/76	A	0728	5.5° ± 0.5°	10.8°
	B		4.8° ± 0.5°	9.5°
	C		6.0° ± 0.5°	10.8°
	D		5.5°	10.5°
	E		4.2°	8.5°
	F		5.5°	10.0°
	G			10.0°
	A	0842	9.8° ± 0.1°	10.6°
	B		10.8° ± 0.2°	9.6°
	C		9.8° ± 0.2°	10.7°
	D		9.5° ± 0.1°	10.5°
	E		11.0° ± 0.6°	8.8°
	F		11.2° ± 0.5°	10.1°
	G		9.8° ± 0.1°	10.5°
	A	0939	14.0° ± 1.0°	10.9°
	B		20.0° ± 1.0°	10.2°
	C		21.0° ± 2.0°	10.1°
	D	0943	13.0° ± 1.0°	11.0°
	E		17.0° ± 3.0°	10.2°
	F		24.0° ± 2.0°	11.0°
	G		12.0° ± 0.5°	11.7°
	A	1326	28.0° ± 3.0°	16.1°
	B		41.0° ± 5.0°	19.1°
	C		48.0° ± 2.0°	18.8°
	D		36.0° ± 3.0°	16.5°
	E		39.0° ± 2.0°	20.2°
	F		42.0° ± 4.0°	18.1°
	G		38.5° ± 3.0°	

APPENDIX E (continued)

	LOCATION	TIME	SURFACE	2" (C°C)
	A	1451	27.0° ± 2.0°	18.3°
	B		45.0° ± 5.0°	22.0°
	C		46.0° ± 5.0°	21.0°
	D		40.0° ± 3.0°	19.2°
	E		40.0° ± 4.0°	23.0°
	F		38.0° ± 4.0°	19.9°
	G	1453	42.0° ± 6.0°	22.9°
	A	1606	32.0° ± 1.0°	19.8°
	B		38.0° ± 2.0°	22.9°
	C		43.0° ± 2.0°	22.1°
	D		45.0° ± 1.0°	20.9°
	E		40.0° ± 2.0°	23.8°
	F		34.5° ± 0.5°	20.3°
	G		35.0° ± 0.5°	22.5°
	A	1702	24.0° ± 0.5°	
	B	1704	32.0° ± 2.0°	22.0°
	C	1704	30.0° ± 1.0°	22.4°
	D	1710	33.0° ± 2.0°	21.0°
	E	1710	37.0° ± 1.0°	20.3°
	F	1710	28.0° ± 1.0°	20.0°
	G		24.0° ± 1.0°	
	A	2117	11.0° ± 0.5°	16.0°
	B		12.0° ± 0.5°	16.0°
	C		13.0° ± 0.5°	16.5°
	D		12.0° ± 0.5°	16.5°
	E		11.5° ± 0.5°	15.5°
	F		11.5° ± 0.5°	15.5°
	G		13.0° ± 0.5°	15.0°
10/14/76	A	0027	10.5° ± 0.7°	14.9°
	B		11.0° ± 0.5°	13.9°
	C		11.7° ± 0.5°	14.9°
	D		11.0° ± 0.2°	14.3°
	E		10.0° ± 0.5°	13.2°
	F		10.8° ± 0.2°	14.2°
	G	0029	11.8° ± 0.2°	13.8°

APPENDIX E (continued)

LOCATION	TIME	SURFACE	2" (°C)
A	0454	10.0° ± 0.1°	12.9°
B		10.3° ± 0.1°	12.2°
C		11.0° ± 0.1°	13.1°
D		10.5° ± 0.1°	12.9°
E		10.0° ± 0.2°	11.8°
F		9.8° ± 0.1°	12.8°
G		10.8° ± 0.1°	12.3°
A	0826	9.5° ± 0.5°	12.0°
B		10.5° ± 0.5°	11.3°
C		11.0° ± 0.2°	12.2°
D		10.2° ± 0.2°	12.1°
E		10.5° ± 0.2°	10.8°
F		13.0° ± 1.0°	12.0°
G	0828	10.5° ± 2.0°	11.4°
A	0917	12.5° ± 1.5°	12.0°
B		15.5° ± 1.0°	11.8°
C		16.5° ± 2.0°	12.3°
D		12.2° ± 0.2°	12.1°
E		13.5° ± 1.5°	11.7°
F		21.0° ± 1.5°	12.0°
G	0920	12.0° ± 0.5°	12.2°

REFERENCES

Goetz, A. F. H., Billingsley, F. C., Gillespie, A. R., Abrams, M. J., Squires, R. L., Shoemaker, E. M., Lucchitta, I., and Elston, D. P., "Application of ERTS Images and Image Processing to Regional Geologic Problems and Geologic Mapping in Northern Arizona", Jet Propulsion Laboratory Technical Report 32-1597, 1975.

Njoku, E. and Yamane, N., JPL Field Measurements at the Finney County Kansas Test Site, Oct., 1976: Microwave Ground-Based Radiometric Observations and Surface Truth, Jet Propulsion Laboratory Tech. Memo (to be published 1977).