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SOLAR RADIATION MEASUREMENTS AND DATA ANALYSIS FOR GAINESVILLE

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ABSTRACT

Global and Diffuse Insolation measurements were made for Gainesville (Latitude 29.65^{o} N) for the months of July, August, September, October and most of November 1983. The data are presented and analysed in this report. A relationship between K_D, the ratio of diffuse radiation to global radiation, and K_T the ratio of global radiation to extra-terrestrial radiation of the following form was obtained

$$K_D = - 1.75\ K_T + 1.36$$

using the method of least squares. The above expression was found to agree very well with the Liu and Jordan Model for values of K_T in the following range: $0.39 \leq K_T \leq 0.70$.

TABLE OF CONTENTS

	PAGE
TITLE	i
ACKNOWLEDGEMENT	ii
ABSTRACT	iii
TABLE OF CONTENTS	iv
INTRODUCTION	1
MEASUREMENT AND INSTRUMENTATION	3
THEORY OF SOLAR RADIATION	5
RESULTS AND ANALYSIS	39
DISCUSSION	42
CONCLUSION	43
REFERENCES	44

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1. INTRODUCTION

In the applications for solar energy to practical systems, the most important goal is the ability to predict output from a proposed design application and thereby establish the value of the energy that is delivered at an economically fair price for the system. To this end the system designer must not only possess adequate technical and engineering know how, but also must have a reliable assessment of the solar energy potential in the location of interest under various seasonal and weather conditions.

This report is the result of a group project that was carried out by some members of the Eighth Session of the Training in Alternative Energy Technologies in Gainesville. The objective of the project was to assess the solar radiation resource through actual daily measurements of insolation over several months, and then to analyse and present the data in a useful form accounting for seasonal and weather variations.

A similar work was undertaken by some participants in the Seventh Session (2) and their report presented useful insolation data for the period January 1980 to July 1982. But their report did not discuss some striking descrepancies between actual measurement data and theoretical insolation calculations. However, in the present report we intend to discuss such descrepancies.

Furthermore, the scope of the data base will not only be extended to include the period July 1983 to November 1983, but also will be expanded to show data for both direct and diffuse solar radiation.

It is important to clearly define the two terms used above for solar radiation.

Direct Radiation: This refers to the solar flux arriving at the collector without having suffered any scattering in traversal of the atmosphere. The radiation is from the geometrical disc of the sun. It is this component of sunlight that is focused by an optical system (or a concentrating collector) into an image of the disc of the sun.

Diffuse Radiation: The atmosphere produces a diffuse component of scattered light through Rayleigh scattering and dust and aerosol scattering. Clouds also scatter sunlight, which add to the total scattered flux but is not strictly diffuse in nature. Also, ground surfaces scatter sunlight, adding to the total flux arriving at the collector. Diffuse radiation cannot be focused by any optical (or concentrating) system, but it does contribute flux to flat-plate and other non-concentrating collectors.

The sum of direct and diffuse radiations is referred to as total or global radiation.

In the present project, total radiation and diffuse radiation were measured at the TREEO Centre in Gainesville using available instruments, as discussed in Section 2. Data was obtained for

total radiation for the months August, September, October and part of November, 1983 while for diffuse radiation, data was obtained for part of October and part of November due to the fact that the shaded-band pyranometer was not ready for use until then.

2. MEASUREMENT AND INSTRUMENTATION

The instruments used for gathering solar radiation data are pyranometer, shaded-band pyranometer and a strip-chart recorder. The pyranometer measures the total solar radiation from the direct rays as well as from the rays scattered by the entire hemisphere viewed by the instrument. The pyranometer was placed in a horizontal position on the roof facing due south, and there was no interference by nearby buildings, trees or bright reflecting objects which could cause erroneous readings. The detector in the Eppley pyranometer has concentric white and black rings to generate a temperature difference, which is measured by multiple-junction thermocouples. The signal appears in the form of milli-volts of electricity which is fed directly into the strip-chart recorder and an instantaneous plot of solar radiation is made. The instrument must be properly calibrated.

A second pyranometer was modified with a shading-band to exclude direct sunlight and thereby enable measurement of the diffuse component of sunlight. When the quantity is subtracted from the reading of the previous pyranometer, the result is a measure of direct solar radiation. The shading-band is made narrow to minimize the obscuration of the sky while shading off direct sunlight. Thus it is necessary to adjust

the position of the band every few days to keep the shadow centered on the pyranometer as the sun's declination angle changes. The signal from this pyranometer is also fed directly to the strip-chart recorder for instantaneous measurement of diffuse radiation. As discussed in section 4.5, a correction factor is applied to the readings from the shading-band pyranometer to adjust for the small amount of diffuse radiation that is inevitably blocked along with the direct radiation.

As the paper advances at a rate of 1 inch per hour, the recorder pens continuously sketch the solar radiation intensity throughout the day, every day and night of each month. In order to obtain the total solar energy incident on the pyranometer in a given day, a graphical integration is performed on the solar intensity plots using a planimeter. This procedure is repeated for all the days of the month for all the months being considered.

Some additional data are also obtainable from the strip-chart plots, and these are sunrise time, sunset time, length of daylight, clear days, not-so-clear days, and cloudy days.

The two pyranometers used are model PSP SN 19326F3 whose constant $K = 9.99 \times 10^{-6} v/Wm^{-2}$ (global radiation) and model 8-48 SN 23501 whose calibration constant $K = 8.17 \times 10^{-6} v/Wm^{-2}$ (Diffuse radiation).

The conversion factors for determining the solar insolation from the area measured by the planimeter are as follows:

a) for British unit planimeter
   Horizontal scale = 1 in/hr
   Vertical scale = 2 mv/in
   1 sq. in = 2 mv hr.
   For $K = 9.99 \times 10^{-6} \frac{v}{Wm^{-2}}$

This gives 1 sq. in = 63.5 BTU/ft^2

The conversion factor $1 \frac{BTU}{HR.\ Ft^2} = 3.153\ Wm^{-2}$ has been used which is a standard conversion factor.

B) For metric unit planimeter
Horizontal scale = 1 in/hr
Vertical scale = 2 mv/in
1 sq. in. = 6.45 cm^2 = 63.5 $\frac{BTU}{ft^2}$
1 cm^2 = 9.845 $\frac{BTU}{ft^2}$

3. THEORY OF SOLAR RADIATION

The amount of solar energy received per unit of time per unit of collector area at the mean distance of the earth from the sun on a surface normal to the sun is called the solar constant. This quantity is difficult to measure from the surface of the earth because of the effects of the atmosphere. Measurements from satellites have improved the situation, and the current value of extraterrestrial solar constant is 1.3530 KW/M^2.

3·1 Above the atmosphere (extraterrestrial) the intensity of sunlight shows a small variation due to changes in the distance of the earth from the sun owing to a small ellipticity of the earth's orbit around the sun. The seasonal variation amounts to -3.27% at aphelion (date at which the sun is furthermost away from earth - July 1) and +3.42% at perihelion (date at which the sun is closest to earth - January 1). The daily variation of extraterrestrial solar flux due to orbital eccentricity can be expressed as

$$Io(n) = Isc \{ 1 + 0.034 \cos (\frac{360n}{365}) \}$$

where $Io(n)$ = solar flux at day n

Isc= solar constant = $1.353 \pm .02$ Kw/m^2

n= day number counting from January 1.

Imagine an extraterrestrial horizontal surface with the sun at a Zenith angle of z (or solar altitude of α).

α = solar altitude
z = solar zenith
$\alpha + z = 90^o$

Then the solar radiation striking the extraterrestrial horizontal surface is

$$Ho = IoCos z = IoSin\ \alpha = Isc(1 + 0.034\ cos\ \frac{360n}{365})Sin\ \alpha$$

at any instant in time determined by α. The solar altitude, α is given by

$$Sin\ \alpha = Sin\ \phi\ Sin\ \delta + Cos\ \phi\ Cos\ \delta\ Cos\ h$$

where ϕ = latitude

δ = declination = $23.45^o\ Sin\left\{360^o\ \left(\frac{284+n}{365}\right)\right\}$

h = hour angle of sun from solar noon

At sunrise and sunset, $\alpha = 0$.

Hence sunrise (hr) and sunset time (hs) are given by

$$\left.\begin{matrix} hr \\ hs \end{matrix}\right\} = Cos^{-1}\ (-\ tan\ \phi\ tan\ \alpha) \qquad \begin{matrix} hs > 0 \\ hr < 0 \end{matrix}$$

In order to calculate the average daily extraterrestrial insolation on a horizontal surface, we integrate Ho from sunrise to sunset, and obtain $\bar{H}o$.

$$\bar{H}o = \frac{24}{\pi}\ Isc\ (1 + 0.034\ Cos\ \frac{360n}{365})\ (Cos\ \phi\ Cos\ \delta\ Sin\ \ hs + \frac{\pi hs}{180}\ Sin\ \phi\ Sin\ \delta)$$

The above equation enables us to calculate the average daily extraterrestrial insolation on a horizontal surface for each day of the year.

In order to obtain the monthly daily averages, we can proceed in one of two ways:

(i) Calculate $\bar{H}o$ for each day of month. Total them and compute the average.

(ii) Estimate the monthly daily average by calculating the average day of the month, which is given as follows:

MONTH	AVERAGE DAY	n
January	January 17	17
February	February 16	47
March	March 16	75
April	April 15	105
May	May 15	135
June	June 11	162
July	July 17	198
August	August 16	228
September	September 15	258
October	October 15	288
November	November 14	318
December	December 10	344

For Gainesville, latitude $\delta = 29.65^{o}$, the values of Ho are shown in table 1 for each month.

3·2 Within the earth's atmosphere there is a significant modification of the extraterrestrial solar radiation by the presence of absorption bands of water vapor, carbon dioxide and ozone. Their effect is to reduce direct solar radiation reaching the earth's surface. Direct solar radiation is further reduced with decreasing solar altitude. This reduction in intensity is directly preportional to the increase in air mass, and is given empirically by

$$I(z) = Io \exp - c (\sec z)^{s}$$

where $I(z)$ = intensity at Zenith angle, $z = 90^{o} - \alpha$

Io = extraterrestrial solar flux

$c = 0.357$

$s = 0.678$

The global insolation actually received at the surface of the earth comprises the reduced direct radiation and some diffuse radiation, and is less than the extraterrestrial value, depending on the weather conditions ie. clear day, cloudy day, dusty atmosphere, rainy day, windy day, etc.

It is useful to define two quantities for analysis of solar data.

(i) Clearness index $K_T = \frac{\text{Total insolation, } H}{\text{Extraterrestrial insolation, } Ho}$

(ii) $K_D = \frac{\text{Diffuse Insolation, } H_S}{\text{Total insolation, } H}$

By measuring H and H_S in a given location, we can then calculate K_T and K_D for each month or season.

Based on the extensive work of several researchers, atmospheric conditions at a given location may be classified as Desert, Standard, Urban, and reference values given for both direct and diffuse solar flux at sea level, at solar Zenith in KW/M^2.

TABLE 2

ATMOSPHERE	Hd Direct	Hs Diffuse	H Total	K_T	K_D
Extraterrestrial	1.353	-	1.353	1.00	0.0
Desert	0.970	0.08	1.050	0.776	0.08
Standard	0.930	0.10	1.030	0.761	0.10
Urban	0.61	0.10	0.81	0.599	0.25

To obtain corresponding values at different Zenith angles, multiply the solar flux by the exponential factor $\exp - c(\sec z)^S$ which accounts for air mass.

The effect of elevation on the value of solar flux can also be estimated as follows:

$$I\ (z,h) = Io\ (1-ah)\ \exp - c(\sec z)^S + ahIo$$

Where $a = 0.14\ Km^{-1}$ and h is the elevation in Km. This relationship is useful for a few Km altitude.

An alternative approach to calculating direct solar radiation attenuation due to atmospheric turbidity (ref) is as follows, at sea level and unity air mass ($z = 0$) in Kw/M^2.

TABLE 3

ATMOSPHERE	Hd Direct	Hd/Ho $\frac{\text{Direct}}{\text{Ext.}}$
Extraterrestrial	1.353	1.00
Very Clear Air	0.956	0.707
Normal Clear Air	0.925	0.684
Pulluted Air	0.889	0.657
Heavy Industrial	0.800	0.591

3·3 Based on the Liu Jordan model for solar radiation, we can utilize some relationships between direct, diffuse and total radiations as follows:

Ho = extraterrestrial radiation on daily basis.

H = actual total insolation on daily basis

H_d = direct insolation on daily basis

H_s = diffuse insolation on daily basis

$H = H_d + H_s$

$K_T = \frac{H}{Ho}$ $\quad K_D = \frac{H_s}{H}$

For $0.30 \leq K_T \leq 0.85$

we have $\frac{Hd}{Sin\alpha} = -520 + 1800\ K_T$ Watts/M^2

For $K_T < 0.30$ we have $H_d = 0$

Alternatively, to obtain diffuse radiation, we have

$K_D = \frac{Hs}{H} =$	$1.0 - 0.249\ K_T$	for $K_T < 0.35$	- cloudy day
	$1.557 - 1.84\ K_T$	for $\leq 0.35 \leq K_T$ 0.75	- normal day
	0.177	for $0.75 < K_T$	- very clear day

3.4 For monthly daily averages, we use the relationship

$$\overline{K}_T = \frac{\overline{H}}{\overline{Ho}}$$

and

$$\overline{K}_D = \frac{Hs}{\overline{H}} = 1.00 - 1.13\ K_T$$

TABLE 1

DAILY EXTRATERRESTRIAL INSOLATION FOR GAINESVILLE o=29.65°
BTU/FT^2-DAY

	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
1.	1759	2050	2502	3020	3379	3555	3569	3432	3118	2654	2140	1801
2.	1764	2064	2519	3035	3388	3558	3567	3425	3104	2637	2125	1795
3.	1769	2078	2537	3049	3396	3561	3564	3418	3091	2620	2111	1788
4.	1774	2092	2554	3064	3404	3563	3562	3410	3077	2603	2096	1782
5.	1779	2107	2572	3078	3412	3565	3560	3402	3063	2586	2082	1777
6.	1785	2121	2589	3092	3420	3567	3557	3395	3049	2568	2068	1771
7.	1791	2136	2607	3106	3428	3569	3555	3386	3035	2551	2054	1766
8.	1798	2152	2624	3120	3435	3571	3552	3378	3021	2534	2041	1762
9.	1805	2167	2642	3133	3443	3573	3549	3369	3006	2517	2027	1758
10.	1812	2182	2659	3147	3450	3574	3545	3361	2992	2500	2014	1754
11.	1820	2198	2676	3160	3456	3575	3542	3352	2977	2483	2001	1750
12.	1828	2214	2694	3173	3463	3576	3539	3343	2962	2466	1988	1747
13.	1836	2230	2711	3186	3469	3577	3535	3333	2947	2448	1976	1744
14.	1844	2246	2728	3198	3476	3578	3531	3324	2931	2431	1964	1742
15.	1853	2263	2745	3210	3482	3579	3527	3314	2916	2414	1952	1739
16.	1862	2279	2762	3223	3487	3579	3523	3304	2900	2398	1940	1738
17.	1872	2296	2779	3235	3493	3580	3519	3294	2885	2381	1929	1736
18.	1882	2312	2796	3246	3499	3580	3514	3283	2869	2364	1918	1735
19.	1892	2329	2813	3258	3504	3580	3509	3273	2853	2347	1907	1735
20.	1902	2346	2830	3269	3509	3580	3505	3262	2837	2330	1897	1734
21.	1913	2363	2846	3280	3514	3580	3500	3251	2821	2314	1886	1734
22.	1924	2380	2863	3291	3518	3579	3494	3240	2804	2297	1877	1735
23.	1936	2397	2879	3302	3523	3579	3489	3229	2788	2281	1867	1736
24.	1947	2415	2895	3312	3527	3578	3483	3217	2772	2265	1858	1737
25.	1959	2432	2911	3322	3531	3577	3478	3205	2755	2249	1849	1738
26.	1971	2449	2927	3332	3535	3576	3472	3193	2738	2233	1840	1740
27.	1984	2467	2943	3342	3539	3575	3466	3181	2722	2217	1832	1743
28.	1996	2484	2959	3351	3543	3573	3459	3167	2705	2201	1824	1745
29.	2009	----	2974	3361	3546	3572	3453	3156	2688	2186	1816	1748
30.	2022		2990	3370	3549	3570	3446	3144	2671	2170	1809	1752
31.	2036		3005		3552		3439	3131		2155		1755
AVE.	1875	2259	2759	3209	3480	3573	3516	3296	2903	2400	1956	1752

TABLE 4

SOLAR RADIATION IN BTU/FT^2-DAY FOR JULY 1983
(N.B. Circled readings were discarded in Computing averages)

DATE	1st READING	2nd READING	3rd READING	DAILY RADIATION
7.1.83	1365	1498	1521	1461
7.2.83	1377	1398	1342	1372
7.3.83	2329	2321	--	2325
7.4.83	1407	1412	1405	1406
7.5.83	2008	2005	2001	2005
7.6.83	NO	DATA	AVAILABLE	
7.7.83	1250	1236	--	1243
7.8.83	1615	1505	--	1560
7.9.83	2392	2215	--	2304
7.10.83	2402	2560	--	2481
7.11.83	2225	2215	--	2220
7.12.83	2107	2038	--	2072
7.13.83	1215	1240	1327	1261
7.14.83	2004	1918	1895	1939
7.15.83	2153	2194	2174	2174
7.16.83	2219	2300	2282	2267
7.17.83	2336	2258	2268	2287
7.18.83	2141	2144	2128	2143
7.19.83	1914	2020	2018	2019
7.20.83	1791	1764	1723	1778
7.21.83	2096	2077	2087	2087
7.22.83	2087	2043	2072	2080
7.23.83	1218	1215	1199	1211
7.24.83	2031	2153	2024	2069
7.25.83	1818	1712	1752	1761
7.26.83	1751	1651	1682	1695
7.27.83	2235	2205	2166	2202
7.28.83	1905	1881	1983	1924
7.29.83	2136	2176	2107	2140
7.30.83	1644	1595	1674	1638
7.31.83	1634	1575	1664	1624

TABLE 5

SOLAR RADIATION IN BTU/FT.^{2}-DAY FOR AUGUST 1983

DATE	1st READING	2nd READING	3rd READING	DAILY RADIATION
8.1.83	2048	2058	---	2053
8.2.83	1723	1713	---	1718
8.3.83	1575	1524	---	1550
8.4.83	1959	1949	---	1954
8.5.83	1654	1644	---	1649
8.6.83	1326	1236	---	1281
8.7.83	1576	1631	---	1604
8.8.83	1575	1538	---	1557
8.9.83	1836	1867	---	1852
8.10.83	1593	1638	---	1616
8.11.83	--	--	---	1271
8.12.83	--	--	---	784
8.13.83	--	--	---	1605
8.14.83	--	--	---	1138
8.15.83	--	--	---	2096
8.16.83	2005	1983	1985	1984
8.17.83	1657	1635	1639	1637
8.18.83	1654	1726	1732	1729
8.19.83	1844	1836	---	1840
8.20.83	1698	1723	1718	1721
8.21.83	1853	1835	1856	1848
8.22.83	1616	1642	1598	1619
8.23.83	2059	2108	2088	2085
8.24.83	1862	1835	1853	1850
8.25.83	1633	1724	1763	1707
8.26.83	2037	1994	1939	1990
8.27.83	1832	1813	1815	1820
8.28.83	1644	1623	1619	1629
8.29.83	INCOMPLETE	DATA	---	--
8.30.83	1201	1181	---	1191
8.31.83	965	925	---	945

TABLE 6

SOLAR RADIATION IN BTU/FT. 2-DAY FOR SEPTEMBER 1983

DATE	1st READING	2nd READING	3rd READING	DAILY RADIATI
9.1.83	418	418	---	418
9.2.83	650	620	---	635
9.3.83	985	994	---	989
9.4.83	1772	1752	---	1732
9.5.83	2149	2104	2137	2130
9.6.83	1622	1675	1591	1629
9.7.83	1446	1850	1855	1717
9.8.83	1146	1142	1153	1147
9.9.83	1717	1845	1855	1817
9.10.83	1713	1703	---	1708
9.11.83	1329	1344	---	1337
9.12.83	1337	1349	---	1344
9.13.83	128	138	---	133
9.14.83	1078	1078	---	1078
9.15.83	1467	1477	---	1472
9.16.83	1831	1841	---	1836
9.17.83	423	433	423	428
9.18.83	1090	1057	1051	1066
9.19.83	1324	1316	1280	1307
9.20.83	894	951	863	903
9.21.83	797	835	903	845
9.22.83	1840	1824	1819	1828
9.23.83	1916	1977	1963	1952
9.24.83	---- NO	DATA AVAILABLE	----	----
9.25.83	-----	-----	----	----
9.26.83	1463	1481	1477	1474
9.27.83	1340	1842	----	1841
9.28.83	1589	1609	1610	1610
9.29.83	1463	1451	1452	1452
9.30.83	1621	1607	1622	1622

TABLE 7

SOLAR RADIATION IN BTU/FT.^{2}-DAY FOR OCTOBER 1983

DATE	1st READING	2nd READING	3rd READING	DAILY RADIATION
10.1.83	1545	1112	1118	1256
10.2.83	1513	1553	1533	1533
10.3.83	1513	1591	1340	1481
10.4.83	1691	1688	1673	1684
10.5.83	1628	1539	1518	1562
10.6.83	1151	1121	1071	1114
10.7.83	1480	1516	1556	1517
10.8.83	1237	1245	----	1241
10.9.83	1034	1053	----	1044
10.10.83	1408	1418	----	1413
10.11.83	1053	1048	----	1051
10.12.83	1211	1221	----	1216
10.13.83	640	551	----	596
10.14.83	384	413	----	394
10.15.83	246	226	----	236
10.16.83	1418	1396	----	1407
10.17.83	738	679	----	709
10.18.83	1145	1390	1222	1252
10.19.83	1157	1065	1085	1103
10.20.83	1304	1452	1256	1337
10.21.83	551	513	530	531
10.22.83	428	424	454	436
10.23.83	-----DATA	ILLEGIBLE	----	----
10.24.83	806	794	799	800
10.25.83	1528	1527	----	1528
10.26.83	1458	1449	----	1454
10.27.83	1563	1566	----	1565
10.28.83	---- NO	DATA AVAILABLE	-----	----
10.29.83	1408	1423	----	1416
10.30.83	1429	1429	----	1429
10.31.83	984	977	----	981

TABLE 8

DIFFUSE RADIATION IN BTU/FT ^{2}-DAY FOR THE LATTER PART OF OCTOBER

DATE	1st READING	2nd READING	3rd READING	DAILY DIFFUSED
10.26.83	338	341	340	340
10.27.83	212	209	211	211
10.28.83	--NO	DATA AVAILABLE	----	----
10.29.83	297	315	319	317
10.30.83	241	236	241	241
10.31.83	559	559	----	559

TABLE 9

SOLAR RADIATION IN BTU/FT ^{2}-DAY FOR NOVEMBER 1983

DATE	1st READING	2nd READING	3rd READING	DAILY DIFFUSED
11.1.83	1013	982	989	986
11.2.83	999	1008	1001	1003
11.3.83	1136	1091	1118	1109
11.4.83	1056	1037	1079	1056
11.5.83	---- NO	DATA AVAILABLE	----	----
11.6.83	----	-----	----	----
11.7.83	150	126	120	132
11.8.83	539	531	521	530
11.9.83	413	417	409	413
11.10.83	796	818	797	797
11.11.83	1364	1372	1381	1372
11.12.83	1349	1366	----	1358
11.13.83	1340	1329	----	1335
11.14.83	1258	1258	----	1258
11.15.83	994	989	994	992
11.16.83	1021	1021	1020	1020
11.17.83	1354	1373	1319	1349
11.18.83	1251	1238	1235	1241
11.19.83	1055	1047	1010	1038
11.20.83	--NO	DATA AVAILABVLE	----	----
11.21.83	1300	1301	----	1301
11.22.83	1275	1277	----	1276
11.23.83	1008	1008	1008	1008
11.24.83	768	768	----	768
11.25.83	1017	1018	1018	1018
11.26.83	999	994	1000	998
11.27.83	994	996	999	997
11.28.83	227	236	253	238
11.29.83	----	----	----	----
11.30.83	----	----	----	----

TABLE 10

DIFFUSE RADIATION IN BTU/FT 2-DAY FOR NOVEMBER 1983

DATE	1st READING	2nd READING	3rd READING	DAILY DIFFUSED
11.1.83	485	497	497	497
11.2.83	483	503	461	484
11.3.83	414	410	403	409
11.4.83	630	632	639	634
11.5.83	445	501	472	473
11.6.83	387	323	322	344
11.7.83	171	162	160	164
11.8.83	421	394	438	418
11.9.83	388	388	---	388
11.10.83	518	514	---	516
11.11.83	231	229	---	230
11.12.83	258	262	---	260
11.13.83	211	211	---	211
11.14.83	276	276	---	276
11.15.83	373	372	373	373
11.16.83	242	249	252	248
11.17.83	241	229	223	231
11.18.83	292	266	283	280
11.19.83	540	536	516	531
11.20.83	--NO	DATA AVAILABLE	---	----
11.21.83	195	191	---	193
11.22.83	213	213	---	213
11.23.83	319	319	---	319
11.24.83	584	584	---	584
11.25.83	211	205	207	207
11.26.83	488	494	490	490
11.27.83	343	343	---	343
11.28.83	175	218	196	196
11.29.83	----	----	----	----
11.30.83	----	----	----	----

TABLE 11

DAILY MEAN AND STANDARD DEVIATION

OF THE GLOBAL SOLAR RADIATION JULY 1983 - AT GAINESVILLE

Date	Daily Mean	Standard Deviation S.D.
7.1.83	1432	66.5
7.2.83	1888	10.5
7.3.83	2325	04.0
7.4.83	1410	02.5
7.5.83	2005	02.9
7.6.83	No Data	----
7.7.83	1243	07.0
7.8.83	1560	54.0
7.9.83	2304	88.5
7.10.83	2481	19.0
7.11.83	2220	05.0
7.12.83	2073	34.5
7.13.83	1261	48.0
7.14.83	1939	46.9
7.15.83	2174	16.7
7.16.83	2267	34.7
7.17.83	2287	34.6
7.18.83	2138	06.9
7.19.83	1984	49.5
7.20.83	1759	27.9
7.21.83	2087	07.8
7.22.83	2067	18.3
7.23.83	1211	06.3
7.24.83	2069	59.2
7.25.83	1761	43.7
7.26.83	1695	41.8
7.27.83	2202	28.3
7.28.83	1923	43.5
7.29.83	2140	28.3
7.30.83	1635	32.6
7.31.83	1624	36.9

TABLE 12

DAILY MEAN AND STANDARD DEVIATION
OF GLOBAL SOLAR RADIATION AUGUST 1983 - AT GAINESVILLE

Date	Daily Mean	Daily Standard Deviation
8.1.83	2053	05.0
8.2.83	1718	05.0
8.3.83	1550	25.5
8.4.83	1954	05.0
8.5.83	1649	05.0
8.6.83	1281	45.0
8.7.83	1604	27.5
8.8.83	1557	18.5
8.9.83	1852	15.5
8.10.83	1616	22.5
8.11.83	1271	00.0
8.12.83	0784	----
8.13.83	1605	----
8.14.83	1138	----
8.15.83	2096	----
8.16.83	1991	09.9
8.17.83	1643	09.6
8.18.83	1703	35.2
8.19.83	1840	04.0
8.20.83	1713	10.8
8.21.83	1848	09.3
8.22.83	1619	18.0
8.23.83	2085	20.0
8.24.83	1850	11.0
8.25.83	1707	54.0
8.26.83	1990	40.0
8.27.83	1820	08.5
8.28.83	1628	10.5
8.29.83	----	----
8.30.83	1191	10.0
8.31.83	945	20.0

TABLE 13

DAILY MEAN AND STANDARD DEVIATION
OF GLOBAL SOLAR RADIATION SEPTEMBER 1983 - AT GAINESVILLE

Date	Daily Mean	Daily Standard Deviation
9.1.83	418	00.0
9.2.83	635	15.0
9.3.83	989	04.5
9.4.83	1763	10.0
9.5.83	2130	19.0
9.6.83	1629	34.7
9.7.83	1717	191.6
9.8.83	1147	04.5
9.9.83	1708	05.0
9.10.83	1337	07.5
9.11.83	135	05.0
9.12.83	1078	00.0
9.13.83	1472	05.0
9.14.83	1836	05.0
9.15.83	428	05.0
9.16.83	1066	17.0
9.17.83	1307	19.0
9.18.83	0903	36.0
9.19.83	845	43.8
9.20.83	1828	08.9
9.21.83	1952	26.0
9.22.83	----	----
9.23.83	----	----
9.24.83	1474	07.7
9.25.83	1841	01.0
9.26.83	1559	43.5
9.27.83	1457	04.9
9.28.83	1617	06.8
9.29.83	----	----
9.30.83	----	----

TABLE 14

DAILY MEAN AND STANDARD DEVIATION

OF GLOBAL SOLAR RADIATION OCTOBER 1983 - AT GAINESVILLE

Date	Daily Mean	Daily Standard Deviation
10.1.83	1256	202.7
10.2.83	1533	016.0
10.3.83	1481	104.0
10.4.83	1684	007.8
10.5.83	1562	047.6
10.6.83	1114	032.9
10.7.83	1517	31.0
10.8.83	1241	04.0
10.9.83	1044	09.5
10.10.83	1413	05.0
10.11.83	1051	02.5
10.12.83	595	44.5
10.13.83	398	14.5
10.14.83	236	10.0
10.15.83	1407	11.0
10.16.83	709	29.5
10.17.83	1252	102.3
10.18.83	1102	39.5
10.19.83	1337	83.4
10.20.83	531	15.5
10.21.83	435	13.3
10.22.83	----	-----
10.23.83	800	24.3
10.24.83	1258	00.5
10.25.83	1454	04.5
10.26.83	1565	01.5
10.27.83	----	-----
10.28.83	1416	07.5
10.29.83	1429	00.0
10.30.83	981	3.5
10.31.83	----	-----

TABLE 15

DAILY MEAN AND STANDARD DEVIATION

OF GLOBAL SOLAR RADIATION NOVEMBER 1983 - AT GAINESVILLE

Date	Daily Mean	Daily Standard Deviation
11.1.83	995	13.3
11.2.83	1003	03.8
11.3.83	1115	18.5
11.4.83	1056	15.0
11.5.83	----	----
11.6.83	----	----
11.7.83	0132	12.9
11.8.83	0530	07.4
11.9.83	0413	03.3
11.10.83	0804	10.0
11.11.83	1372	06.0
11.12.83	1358	08.5
11.13.83	1335	05.5
11.14.83	1258	00.0
11.15.83	0992	02.4
11.16.83	1021	00.0
11.17.83	1349	22.4
11.18.83	1242	07.0
11.19.83	1038	19.6
11.20.83	----	----
11.21.83	1301	00.5
11.22.83	1276	01.0
11.23.83	----	----
11.24.83	----	----
11.25.83	----	----
11.26.83	----	----

TABLE 16

COMPUTED VALUES OF K_D AND CLEARNESS INDEX K_T

FOR LATTER PART OF OCTOBER AND MOST OF NOVEMBER

RADIATION MEASURED IN BTU/FT^2 - DAY

DATE	TOTAL RADIATION	DIFFUSE RADIATION	EXTRA TERRESTRIAL RADIATION	$K_D = \frac{\text{DIFFUSE}}{\text{TOTAL}}$	$K_T = \frac{\text{TOTAL}}{\text{EXTRA}}$
10.26.83	1454	340	2271	0.23	0.64
10.27.83	1565	211	2255	0.13	0.69
10.28.83	--Incomplete Data--				
10.29.83	1416	317	2224	0.22	0.64
10.30.83	1429	241	2208	0.17	0.65
10.31.83	981	559	2193	0.57	0.45
11.1.83	986	497	2177	0.50	0.45
11.2.83	1003	484	2162	0.48	0.46
11.3.83	1109	409	2147	0.37	0.52
11.4.83	1056	634	2132	0.60	0.50
11.5.83	----	574	2118	----	----
11.6.83	----	344	2103	----	----
11.7.83	----	164	2089	----	----
11.8.83	530	418	2075	0.79	0.26
11.9.83	413	388	2061	0.94	0.20
11.10.83	797	516	2047	0.65	0.39
11.11.83	1372	230	2033	0.17	0.67
11.12.83	1358	260	2020	0.19	0.67
11.13.83	1335	211	2007	0.16	0.67
11.14.83	1258	276	1994	0.22	0.63
11.15.83	992	373	1982	0.38	0.50
11.16.83	1020	248	1969	0.24	0.52
11.17.83	1349	231	1957	0.17	0.70
11.18.83	1241	280	1945	0.23	0.64
11.19.83	1038	531	1938	0.51	0.54
11.20.83	--Incomplete Data--				
11.21.83	1301	193	1912	0.15	0.68
11.22.83	1276	213	1901	0.17	0.67
11.23.83	1008	319	1891	0.32	0.53
11.24.83	768	584	1880	0.76	0.41
11.25.83	1018	207	1871	0.20	0.54
11.26.83	998	490	1861	0.49	0.54
11.27.83	997	343	1852	0.34	0.53
11.28.83	238	196	1843	0.82	0.13

TABLE 17

CORRECTION FACTOR FOR K_D DUE TO THE DIFFUSE RADIATION INTERCEPTED BY THE SHADOW RING.(A CORRECTION FACTOR OF 1.14 IS USED FOR THE PERIOD 10/26/83-11/10/83 AND 1.12 IS USED FOR THE PERIOD 11/11/83-11/30/83).

DATE	$K_D = \frac{\text{DIFFUSE}}{\text{TOTAL}}$	NEW K_D
10.26.83	0.23	0.26
10.27.83	0.13	0.15
10.29.83	0.22	0.25
10.30.83	0.17	0.19
10.31.83	0.57	0.65
11.1.83	0.50	0.57
11.2.83	0.48	0.55
11.3.83	0.37	0.42
11.4.83	0.60	0.68
11.8.83	0.79	0.90
11.9.83	0.94	1.00
11.10.83	0.65	0.74
11.11.83	0.17	0.19
11.12.83	9.19	0.21
11.13.83	0.16	0.18
11.14.83	0.22	0.25
11.15.83	0.38	0.43
11.16.83	0.24	0.27
11.17.83	0.17	0.19
11.18.83	0.23	0.26
11.19.83	0.51	0.57
11.21.83	0.15	0.17
11.22.83	0.17	0.19
11.23.83	0.32	0.36
11.24.83	0.76	0.85
11.25.83	0.20	0.22
11.26.83	0.49	0.55
11.27.83	0.34	0.38
11.28.83	0.82	0.92

TABLE 18

K_D and K_T values from Liu and Jordan based on equation:

$$K_D = 1.0045 + 0.04349\ K_T - 3.5227\ K_T^2 + 2.6313\ K_T^3\ (K_T \leqslant 0.75)$$

Equation based on the early solar constant value of 442 BTU/HR. FT.^{2}

$K_D = \frac{\text{DAILY DIFFUSE}}{\text{DAILY TOTAL}}$	K_T (DAILY CLEARNESS INDEX)
1.00	0.05
0.98	0.10
0.94	0.15
0.89	0.20
0.84	0.25
0.77	0.30
0.70	0.35
0.63	0.40
0.55	0.45
0.47	0.50
0.40	0.55
0.33	0.60
0.27	0.65
0.21	0.70
0.17	0.75

TABLE 19

Mean global monthly radiation for July, August, September, October and November 1983.

MONTH	MEAN RADIATION IN BTU/FT^2
JULY	1892
AUGUST	1644
SEPTEMBER	1323
OCTOBER	1151
NOVEMBER	984

TABLE 20

Diffuse Radiation in BTU/FT^2 for October (Last Column) derived from Fig. 3 for 0.39 K_T 0.70. Other parameters used to generate data is also included.

DATE	EXTRATER-RESTRIAL	TOTAL RADIATION	K_T	*K_D	DIFFUSE RADIATION
10/1/83	2685	1256	0.47	0.54	678
10/2/83	2669	1533	0.57	0.36	559
10/3/83	2652	1481	0.56	0.38	563
10/4/83	2636	1684	0.64	0.24	404
10/5/83	2619	1562	0.60	0.31	484
10/6/83	2602	1114	0.43	0.60	668
10/7/83	2586	1517	0.57	0.36	546
10/8/83	2569	1241	0.48	0.52	645
10/9/83	2552	1044	0.41	0.64	668
10/10/83	2536	1413	0.56	0.38	537
10/11/83	2519	1051	0.42	0.62	652
10/12/83	2502	1216	0.49	0.50	608
10/16/83	2435	1407	0.56	0.38	535
10/18/83	2402	1252	0.52	0.45	563
10/19/83	2385	1103	0.46	0.55	607
10/20/83	2369	1337	0.56	0.38	508
10/25/83	2287	1528	0.67	0.19	290
10/26/83	2271	1454	0.64	0.24	349
10/27/83	2255	1565	0.69	0.15	235
10/29/83	2224	1416	0.64	0.24	340
10/30/83	2208	1429	0.65	0.22	314
10/31/83	2193	981	0.43	0.60	589

NB DAYS FOR WHICH $K_T < 0.39$ HAVE BEEN EXCLUDED.

* Extrapolated from Fig. 3.

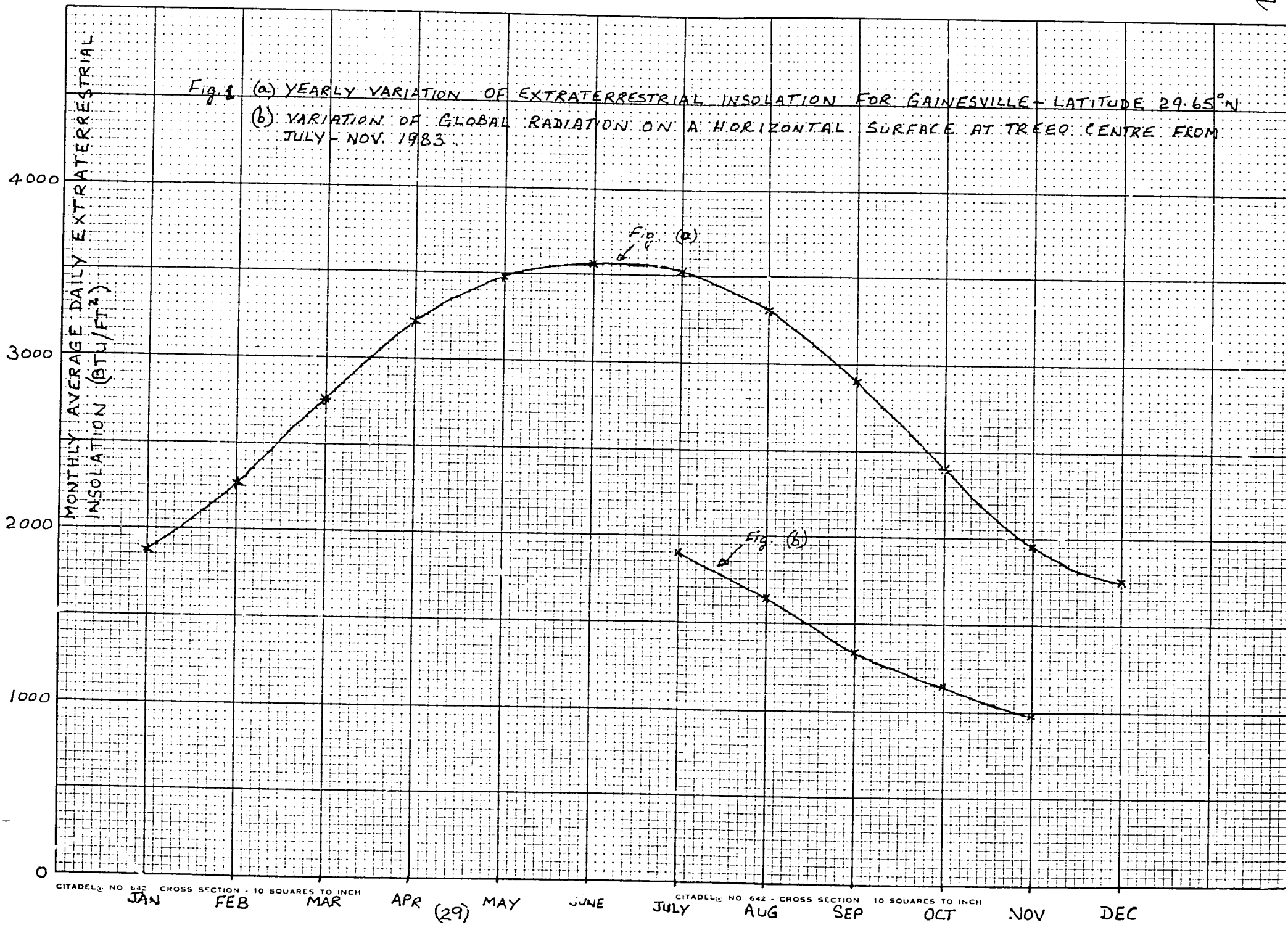
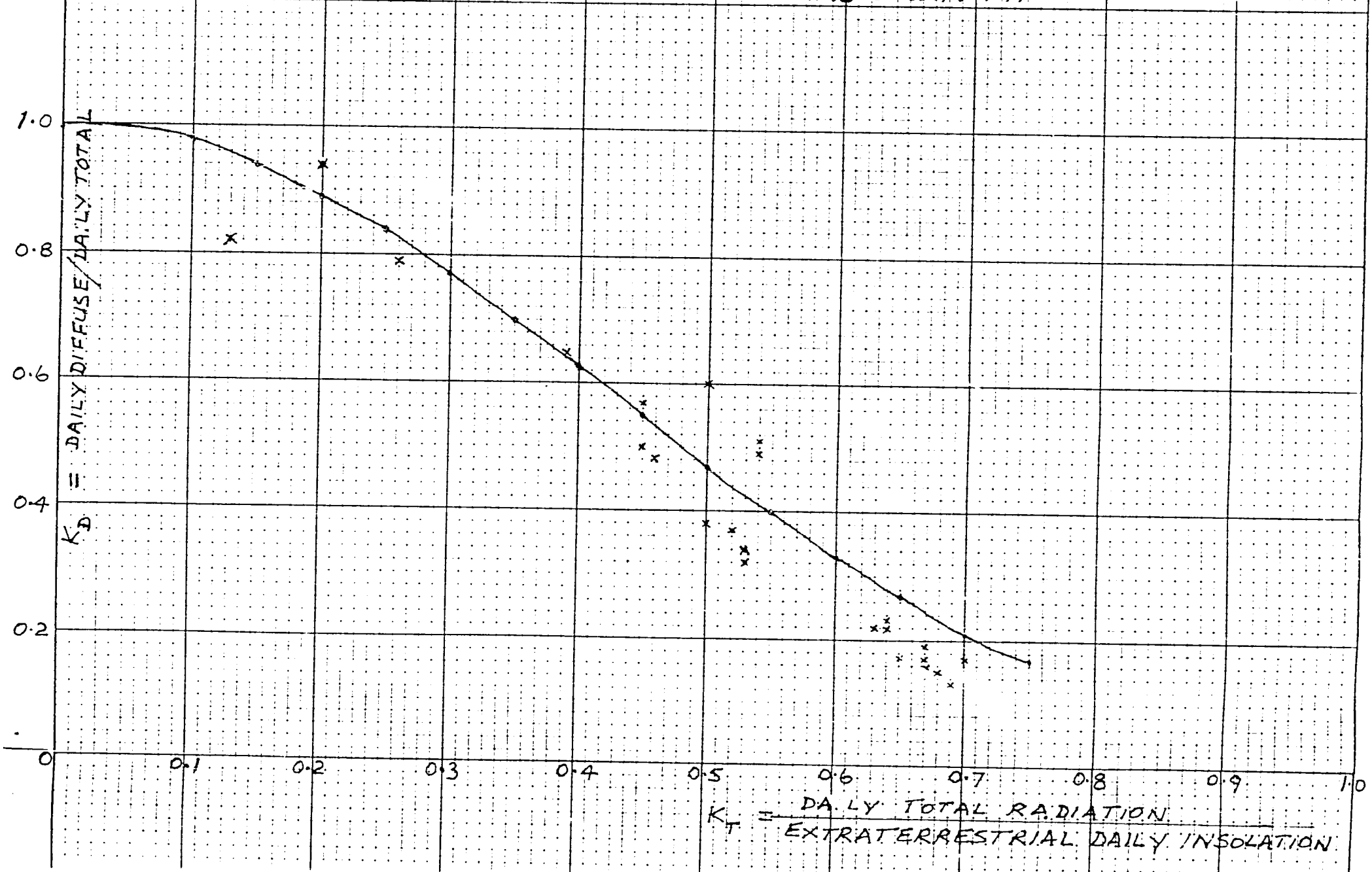


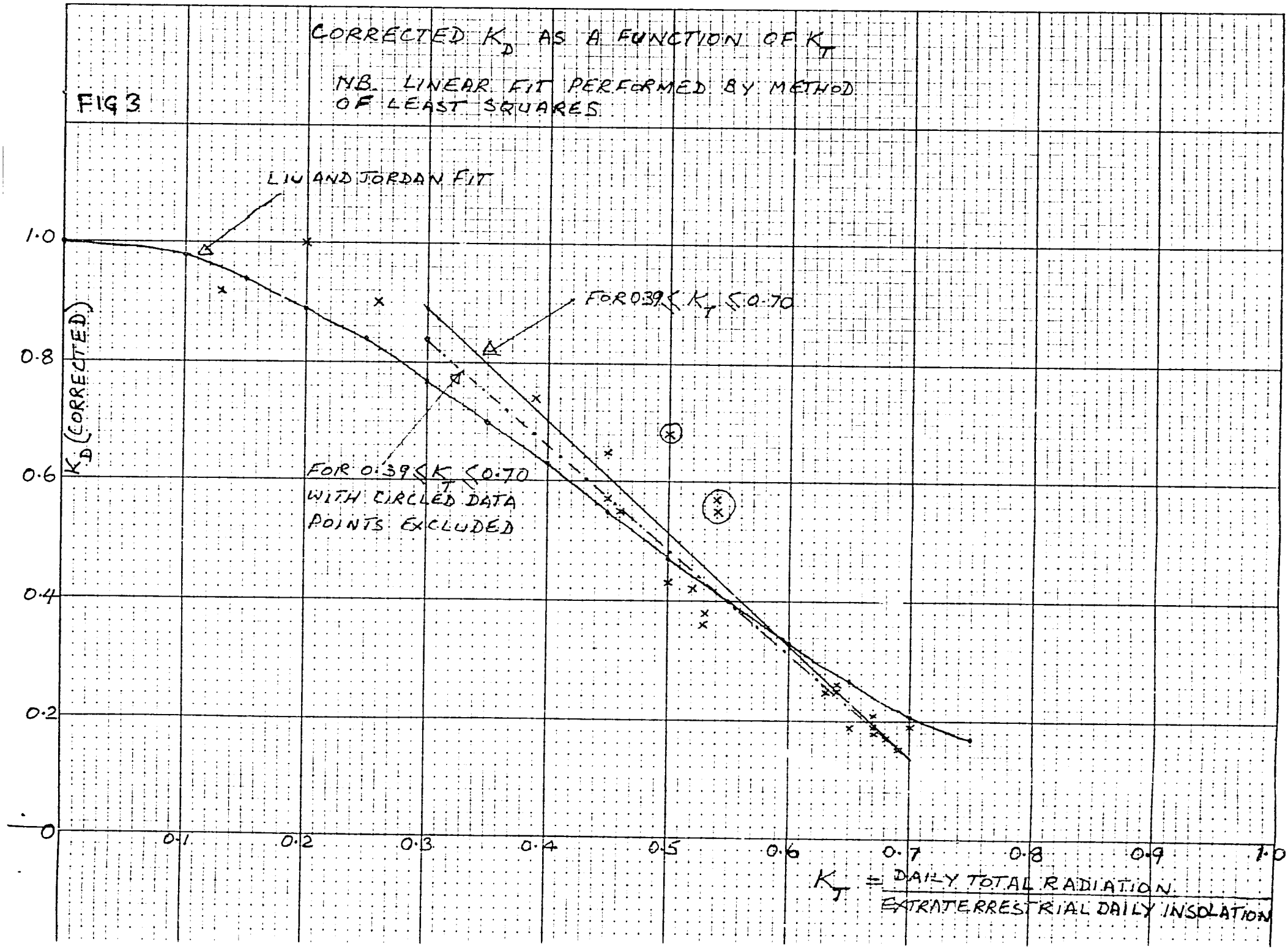
Fig. 1 (a) YEARLY VARIATION OF EXTRATERRESTRIAL INSOLATION FOR GAINESVILLE - LATITUDE 29.65°N
(b) VARIATION OF GLOBAL RADIATION ON A HORIZONTAL SURFACE AT TREEO CENTRE FROM JULY - NOV. 1983.

FIG 2

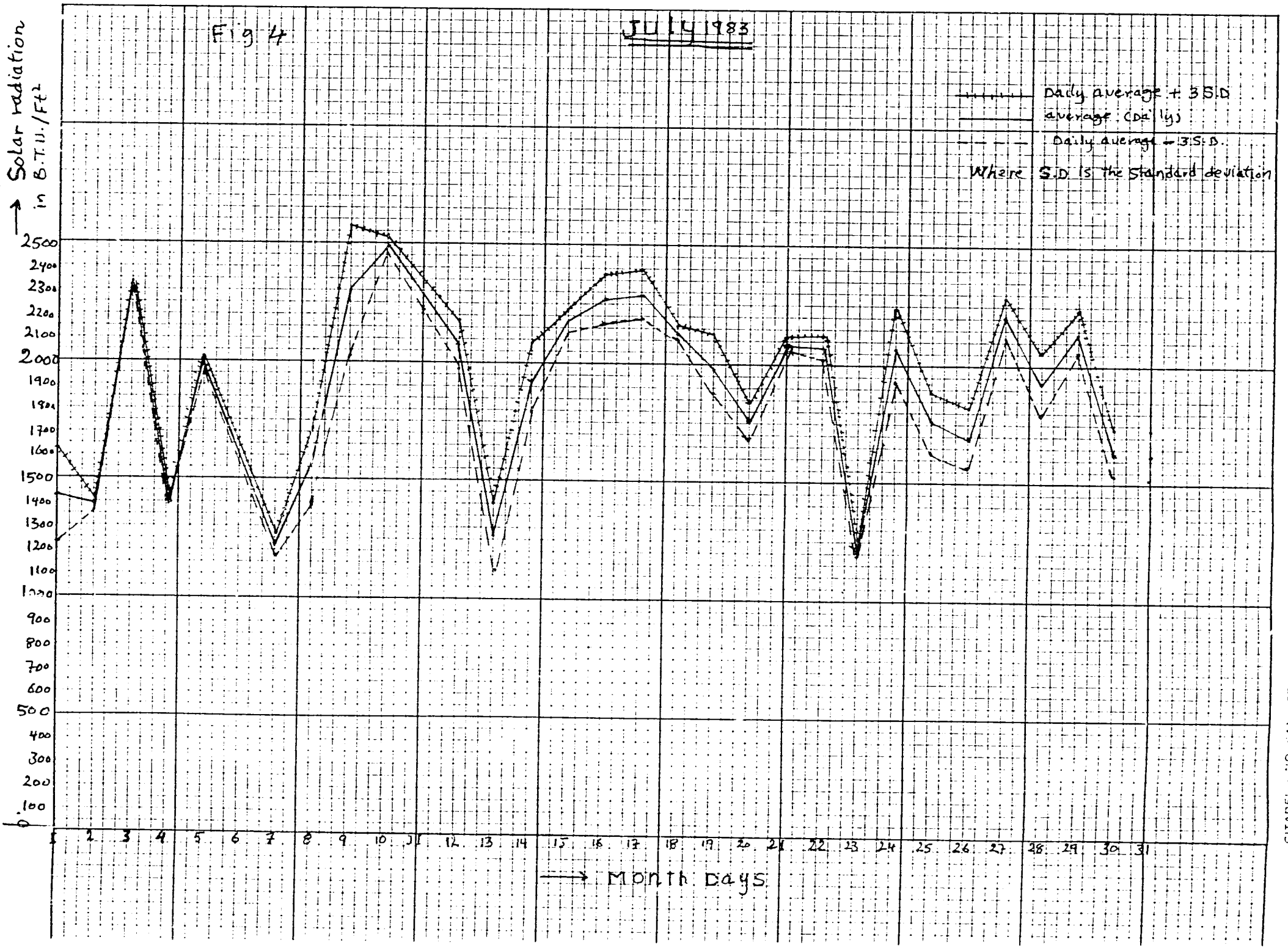
RATIO OF DAILY DIFFUSE RADIATION TO DAILY TOTAL HORIZONTAL RADIATION (K_D) AS A FUNCTION OF CLEARNESS INDEX (K_T)

N.B. THE CONTINUOUS CURVE IS THE LIU AND JORDAN FIT

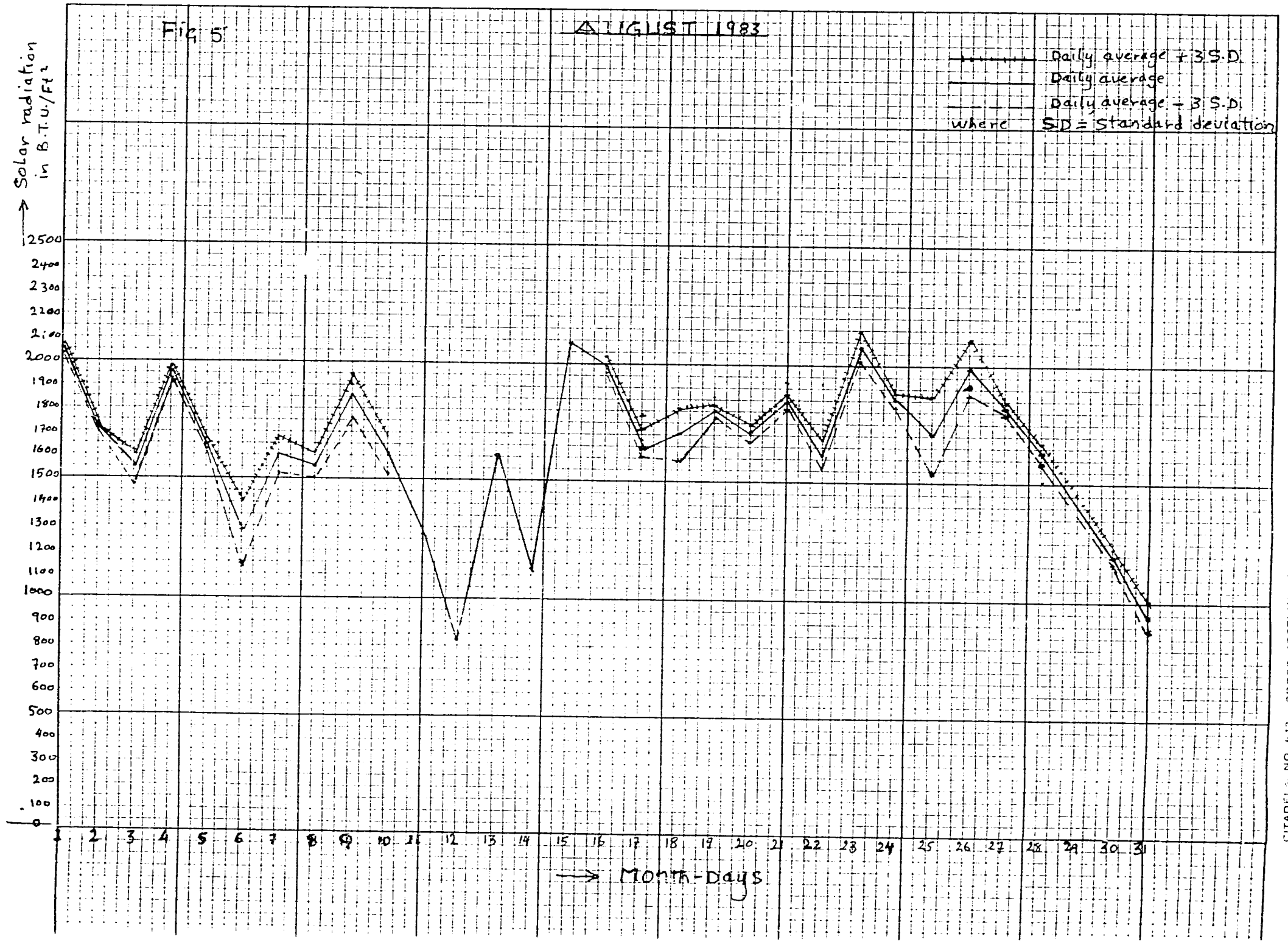




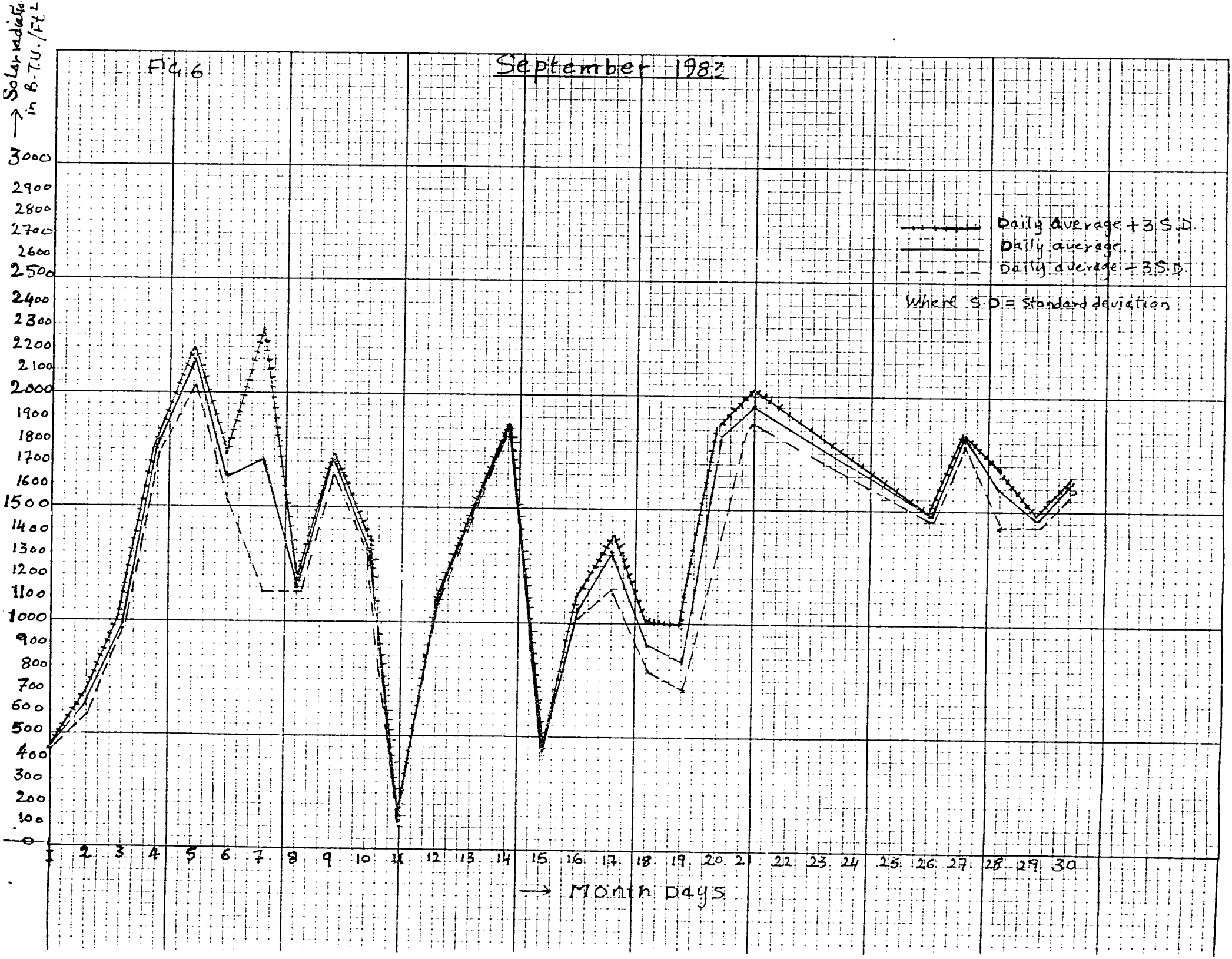
CITADEL NO 942 - CROSS SECTION - 10 SQUARES TO INCH



CITADEL 10 642 · CROSS SECTION · 10 SQUARES TO INCH



CITADEL NO. 642 - CROSS SECTION - 10 SQUARES TO INCH



CITADEL, NO 142 - CROSS SECTION - 10 SQUARES TO INCH

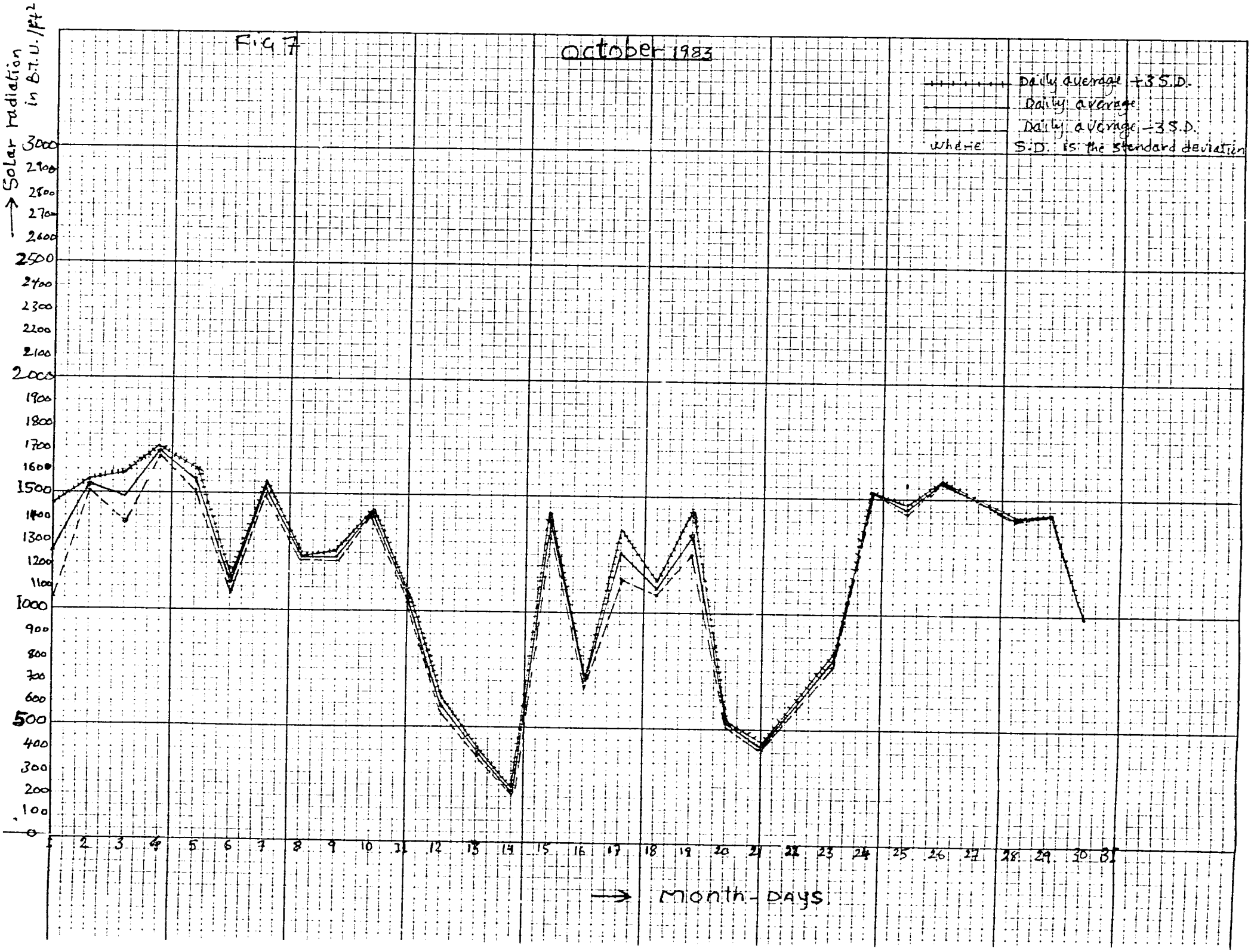
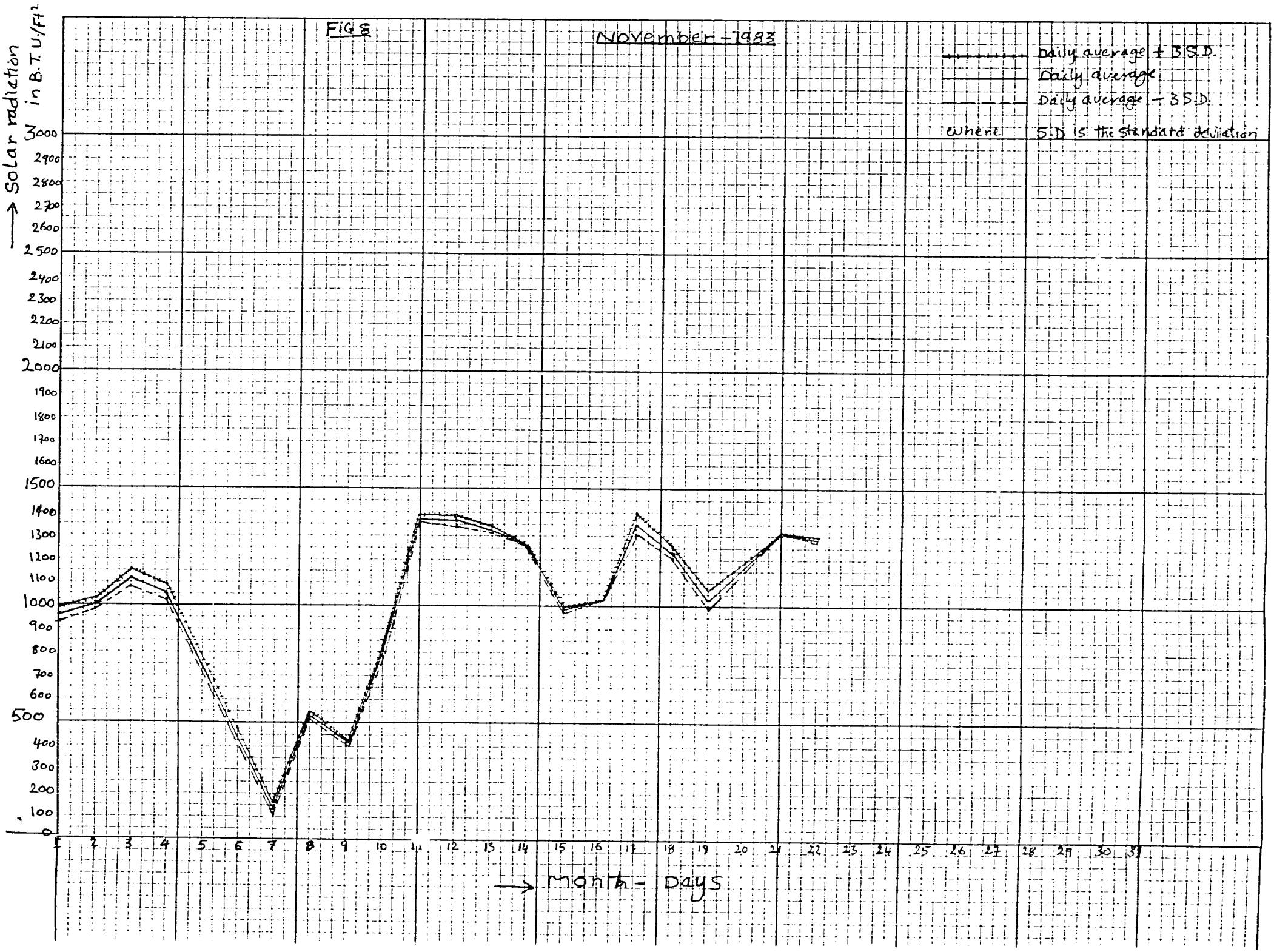


Fig 7
October 1983
Daily average +3 S.D.
Daily average
Daily average -3 S.D.
where S.D. is the standard deviation
Solar radiation in B.T.U./ft²
Month-Days
CITADEL NO. 642 · CROSS SECTION · 10 SQUARES TO INCH



CITADEL NO 142 - CROSS SECTION - 10 SQUARES TO INCH

4. RESULTS AND ANALYSIS

(i) TABLES

4·1 There are seven tables (Table 4 - 10) which show the actual measurements of the global and diffuse radiation for Gainesville (Latitude 29.65^{o} N).

4·2 The area under the curve was measured three times (from the information obtained from the strip chart recorder) for which the radiation was calculated. The mean then represents the total daily radiation. There are five tables (Table 11 - 15) which show the average daily total radiation and the standard deviation taken from 4·1.

4·3 Table 1 shows the daily extraterrestrial radiation for Gainesville including the monthly averages. This table was generated from a program on the Commodore Vic-20 Computer.

4·4 Table 16 shows the K_D and K_T values for the various days in October and November for which measurements of diffuse radiation were available. Some data were deleted from the table because of:

(i) inconsistencies e.g. the diffuse radiation exceeding the global radiation which is not normal and is probably due to instrumentation error. This only occurred on extreme cloudy and rainy days.

(ii) equipment failure.

4·5 Table 17 shows the corrected values of K_D. A correction factor of 1.14 was used for the period 10-26-83 to 11-10-83 and a factor of 1.12 was used for the period of 11-11-93 to 11-30-83. A correction factor is necessary to account for the small portion of di-fuse radiation that is blocked by the shadow band. The values used

were consistent with those suggested by Drummond who did an extensive study of the shadow band correction.

4·6 Table 18 shows K_T and K_D values based on the Liu and Jordan Model, using the equation

$$K_D = 1.0045 + 0.0439\ K_T - 3.5227\ K_T^2 + 2.6313K_T^3$$

for $K_T \leq 0.75$.

This equation was based on an earlier value of 442 BTU/F_T^2HR.

4.7 Table 19 shows the mean global monthly insolation for the months of July, August, September, October and November 1983 for Gainesville.

4.8 Table 20 shows the predicted values of diffuse radiation for October using the method of least squares. The equation from which the table was generated was obtained from a computer program on the Commodore Vic-20 (See Appendix 1). A comparison between the predicted values for some days in October was made with the actual measured diffuse radiation available for these days. These days appear below.

DATE	MEASURED DIFFUSE	PREDICTED DIFFUSE
10-26-83	340	349
10-27-83	211	235
10-29-83	317	340
10-30-83	241	314
10-31-83	559	589

In general, there is a good agreement between the measured and predicted values.

(ii) GRAPHS

4·9 Figure 1 (a) shows the average monthly values of extra-terrestrial radiation on a horizontal surface for Gainesville, and Figure 1(b) shows the average monthly global insolation on a horizontal surface for Gainesville for the months of July, August, September, October, and November 1983.

4·10 Figure 2 shows values of K_D plotted against the corresponding values of K_T for measured data and includes a curve based on the Liu and Jordan Model. No elevation correction was made due to the fact that Gainesville is almost at sea level. Although no shadow band correction was made here, the Liu and Jordan fit shows good agreement with the measured data.

4·11 Figure 3 shows a plot of corrected values of K_D as a function of K_T. The Liu and Jordan curve is also included for comparison. Also shown is two straight lines generated by the method of least squares. The solid line represents the equation

$K_D = -1.89\ K_T + 1.46$ and takes into account all the data points, while the dotted line represents the equation $K_D = -1.75\ K_T + 1.36$ and has the three points encircled deleted.

4·12 Figures 4 through 8 show curves of daily mean global radiation for July, August, September, October and November as indicated on each graph paper, two standard deviations and three standard deviations are added and subtracted (See Section 4·2).

5. DISCUSSION

5·1 We have only five months of global data base and about one month of diffuse data base; this is therefore a continuation of what had been done by a similar group in Session 7. Because of this limited data size we found it unnecessary to engage in long correlations and interpolations to verify the existing theories about global and diffuse radiation. However, the observations we have already made in Section 4 with regard to the relationship between K_D and K_T are valid. Moreover, the least squares fit brought about good results.

5·2 Although we considered only five months, our monthly means come very near with the values obtained for 1980 and 1981 by the previous group.

Month	1980	1981	1982
July	1852	1785	1892
August	1734	1372	1644
September	-	1236	1323
October	1110	1292	1151
November	962	1072	984

6. CONCLUSION

6·1 Based on the results presented and the subsequent discussions, we have reached the following conclusions:

(i) Our measured values of insolation agree fiarly well with previous values for Gainesville.

(ii) We acquired adequate knowledge to conduct a similar work in our countries.

(iii) Our values of K_D and K_T agree very well with the published results in Liu and Jordan.

REFERENCES

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APPENDIX

VIC 20 COMPUTER PROGRAM FOR BEST FIT OF K_D VS K_T DATA POINTS

```
10.  REM BEST FIT OF K_D VS K_T BY METHOD OF LEAST SQUARES
15.  DIM X(23), Y(we): XY=0: SZ=0: SY=0: XX=0
20.  FOR I=1 to 23: READ X(I), Y(I):  NEXT I
30.  FOR I=1 to 23
40.  XY + XY + X(I) * Y(I)
41.  SX = SX + X(I)
42.  SY + SY + Y(I)
43.  XX + XX + X(I)   2
44.  NEXT I
50.  A + (23 * XY - SX *SY)/(23 * XX - SX  2)
60.  B = (SY * XX - SX * XY) / (23 * XX - SX  2)
70.  PRINT A,B
100. DATA  .64, .26, .69, .15, .64, .25, .65, .19, .45, .65
101. DATA  .45, .57, .46, .55,.52, .42, .50, .68, .39, .74
102. DATA  .67, .19, .67, .21, .67, .18, .63, .25, .50, .43
103. DATA  .70, .19, .64, .26, .54, .57, .68, .17, .67, .19
104. DATA  .53, .36, .54, .55, .53, .38
110. END
```