Hourly Variation of the Total Insolation Incident Since Sunrise by Months for the Northern Hemisphere

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Summary

There has long been a need for data showing the diurnal variation of the total insolation for all latitudes and seasons. These data have been prepared, and are presented here with a brief summary of related previous work, methods of calculation, and of applications of the data to forecasting problems.

To Dr. Irving P. Krick, Dr. H. J. Stewart, and Dr. Walter M. Elsasser of California Institute of Technology; Mr. L. H. Daingerfield, and Mr. Joe E. Fulks of the United States Weather Bureau, I wish to express my appreciation for the valuable suggestions and help given me.

History:

The first evaluation of solar radiation for meteorological purposes was done by Angot[4*] who calculated the total amount of heat incident per square centimeter at each 10° parallel of latitude during each month of the year. This work has been very helpful in understanding the general circulation of the atmosphere, and was used by Simpson[19] in his investigations of the problem of mean temperature balance; but it is not applicable to forecasting problems.

Extensive measurements of incident solar radiation have been made by the Smithsonian Institution, by the United States Weather Bureau and various cooperating observatories, and by observatories in several foreign countries. The Smithsonian Institution's observations have been directed primarily toward evaluating the Solar Constant. Their value of 1.94 calories per square centimeter per minute is universally accepted as the best so far obtained.

Radiation observations by the Weather Bureau, on the other hand, have been made for the primary purpose of evaluating the energy available for atmospheric warming. Hence these observations include sky radiation plus that part of the solar beam which reaches the surface. A summary and discussion of these obser-

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* Numbers refer to bibliography

vations has been published by Hand[7]. The effect of different air masses is not considered in computing the data published, nor is the variation in local atmospheric polution. As summarized the observations represent a mean summation of the resultant energy available at each station, and should be very useful for forecasts in the vicinity of the observation stations.* For widespread or general application, some method would have to be worked out for reducing all the observations to some standard, and applying corrections for different types of air mass or local modification.

Work more nearly like the present was done by Lester[13] as a part of his investigation of the problem of forecasting the dissipation of fog in the San Francisco Bay region. He calculated hourly values for the insolation which would be applicable to stratus dissipation in that region. His contribution will be discussed further.

Need for Data:

Many forecasting problems demand that the forecaster make some commitment which presupposes a good knowledge of the amount of heat that will be applied to the air by a given hour of the day. Some of the more obvious of these problems are: At what time will

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* See page 11.

the fog (or stratus) be dissipated? What will the maximum temperature be? At what time will the temperature reach, say, 80?

All of these problems require a knowledge of several quantities besides solar radiation: some have been solved rather well for given localities; but with all of them, it would seem that a general solution would be easier if one value--that is, the amount of solar heat which will have been received by each hour of the day--were known. Once this total incident energy is known, corrections can be made for absorption and reflection of that energy; for the additional heat which will be received from the sky; and for complicating factors such as wind, wetness of the ground, type of air mass, polution, etc.

As a step toward making such forecasts more accurate, the hourly totals for the solar energy incident since sunrise at the outer limits of the atmosphere has been calculated for the fifteenth of each month through the year, for each 10 degrees of latitude for the northern hemisphere.

Method:

The method for obtaining the values is not difficult.[8] It can be shown that:

$$Q = \frac{I}{\omega D^2}\left\{ h \sin\phi \sin\delta + \sin h \cos\phi \cos\delta \right\}\Big|_{h_1}^{h_2}$$

where: Q is the amount of heat (cal./cm.^{2}) which reaches the outer limits of the atmosphere from the sun between the times h_1 and h_2.

I is the solar constant. 1.94 cal/cm^2/ min.

ω is the rate of rotation of the earth.

h is the hour angle. h_0, the hour angle at sunrise, was obtained by the formula:

$$\cos h_0 = -\tan\phi \tan\delta$$

ϕ is the latitude.

δ is the angle of the sun's declination.

D is the radius vector of the earth (correction for distance to the sun).

All times are apparent solar time.

The insolation values are presented in figures 0 to 9.

Use of Data:

In using the data the forecaster must make modifications and corrections according to the situation with which he is dealing. One of the most important questions is: How much of this incident radiation can I assume will be spent in modifying the air over my station? Whatever this fraction is, all the data considered must be multiplied by it before being used for the forecast. To facilitate this, a set of scales can be made to measure effective radiation directly from the graphs. Such a scale is shown in figure 10.

Table 1 contains a suggested list of albedoes (reflected fraction of incident radiation).

For some problems a second correction must be applied to account for the heat lost by radiation from the ground, and for heat gained by radiation from the sky. These can be approximated by use of the empirical equations published by Brunt[3], and Krick[12]; or for more exact work, by using the radiation chart developed by Elsasser[5,6].

Other corrections will have to be made to include the amount and height of cloudiness, evaporation of water, heat contribution or deduction by the ground, advection of warmer or colder air, and perhaps others. The effect of these influences is beyond the scope of this paper, but is considered by Lester[13] and by Neiberger[15]. An approach to the problem using the methods outlined in their papers should yield satisfactory results.

Perhaps the most direct application of the data given here is to the problem of timing the dissipation of stratus. By using methods developed at California Institute of Technology, Lester was able to predict the time at which stratus at Oakland Airport would break within ten minutes.

As an example of the application of this method to a problem at another station, consider the forecast for dissipation of the fog at San Antonio, Texas in the early morning hours of May 7, 1941. The data available by 0535 EST included:

Radiosonde Observation at San Antonio 01 EST 5-7-41

Elev.	P	T	RH	W
2	989	20	87	13.2
4	967	26	73	15.7
7	930	24	76	15.9
16	845	20	52	9.2
24	765	15	37	5.2
38	644	4	29	2.3

Pilot Balloon Observation at San Antonio 23 EST 5-6-41

Alt. Thsd. Feet	Direction	Vel.Mph
Surface	120°	5
1	140°	16
2	160°	15
3	200°	5
4	270°	4
5	320°	6
6	320°	11

Hourly Observations at San Antonio May 7, 1941

ZN	0035	EST	C	O	085/70/66↖5/979	
ZN	0135	EST	C	O	091/67/65↑↖4/981	
ZN	0235	EST	C	O	091/68/65↑↖5/981	
ZN	0335	EST	C	O	088/68/65 ↑ 8/980	
ZN	0435	EST	X	1⊕1/2F	085/68/68↑↖6/979/803	50004
ZN	0458	EST	Spl C	3⦶6F-	088/69/68↑8/980	
ZN	0535	EST	N	3⊕1F-	088/69/68↑8/980	

The synoptic map indicated nothing which would complicate the problem.

The first step is to plot the temperature and dew point curves reported by the San Antonio Raob at 01 EST, before the fog formed. This is shown in figure 11. The structure of the lower levels of the air and the fact that the dew point increased from 65° to 68° when fog was first reported indicate that the stratus was caused by turbulence as well as radiation. Since the moisture content is practically constant through the stratus this gives us some indication of its thickness. If a line of equal mixing ratio is drawn through the surface point (14.8 gr/kg.), the top of the fog will be at the height at which the low level increase in mixing ratio will be balanced by the assumed decrease just above.

Once a reasonable value for the top of the fog has been found (in this case 962 mb.), the temperature curve on the chart can be modified to represent the structure of the air during the fog. This is done by assuming a pseudo-adiabatic lapse rate from the surface to the top of the fog, hence a steep inversion to the intersection with the sounding. The top of the stratus when it breaks will be at the intersection of this inversion line and the constant mixing ratio line as shown. From this intersection a dry adiabatic line is drawn to the surface, where it represents the critical breaking temperature for the stratus (72°F).

In order to tell at what time 72° will be reached, the parallelogram ABCD is constructed as shown (AD and BC are adiabats; AB and CD are isobars). This parallelogram represents the amount of heat that is needed to warm each unit area column of air before the stratus will dissipate. It may be evaluated by estimating its area and knowing how many calories of heat the area represents on a particular chart. A new method for evaluating this energy is outlined as an appendix to this thesis. Using this newer method, the amount of heat needed was found to be 19.6 calories per square centimeter. Reference to figure 3a using the 22% scale, and interpolating between curves for April 15 and May 15, we find that the 19.6 calories should be had by 0800 apparent solar time. San Antonio is 98 28' West Longitude, so a correction of 1 hour 32 minutes is added to give 0932 EST as the time of breaking, which is verified by the following reports:

Hourly Observations at San Antonio 5-7-41

ZN	0635	EST	Spl	N	5⊕M GF-	091/67/66↑↗6/981
ZN	0735	EST		N	5⊕2 GF-	091/68/67↗6/981 THN SPOTS
ZN	0835	EST	Spl	N	7⊕6 GF-	102/69/67↑↗8/984 BRKS
ZN	0935	EST		C	70⊘	095/72/68↑13/982/5[illegible]MVG N
ZN	1035	EST		C	O	105/76/69↑10/985/105 50094

Application to situations with greater complexity should be made possible by the empirical calculation of corrections to be applied to one or another of the values used.

These data can also be used in making maximum temperature forecasts. As an example, consider a forecast for the maximum temperature at Ely, Nevada May 16, 1941: The data available before sunrise indicates that no clouds would be expected, and that the air mass over the station would not change during the day. The upper air sounding gave the following data:

Radiodonde at Ely Nevada, ol EST May 16, 1941.

Elev.	P	T	RH	W
19	812	5	58	4.0
20	804	12	55	5.6
32	692	3	42	2.9
44	601	-7	52	1.9
57	507	-11	39	1.3
71	417	-23	37	0.6

This sounding is shown plotted on an adiabatic chart in figure 12.

If one assumes that under such conditions, 70% of the total insolation will be applied for warming the air, and that the maximum temperature will be reached near 3 p.m. local time, figure 4a (using the 70% scale) shows that 540 calories of heat will be available. It is possible by calculating the amount of heat needed to raise the temperature to several trial values to bring this amount of heat to 540 calories. In this way it is found that a maximum temperature of 76° F is likely.

The maximum temperature reported was 73° F. The cause for the error (though slight) seems to have been the occurrence of cirro-stratus clouds by mid-morning with a gradual increase to four or five tenths by 1630PST.

If the problem be worked again, assuming an average cloudiness of 2/10 of the sky, and hence the 60% application of the total insolation, the results are much better. This new assumption shows 460 calories of heat available, and a maximum temperature of 74° F--as close as graphical methods justify.

As a check on the calculation, let us see by what time of day the temperature should have reached 66° F, the value reported on the 1030 PST report. This is much easier to calculate than the maximum temperature because there is no need for a trial and error solution.

Drawing an adiabat through the surface pressure at 66° F, we find that 326 calories per square centimeter are needed to warm the air to this value. Going again to figure 4a and using the 60% scale, we find that this amount of heat should be available by 1035 apparent solar time. This is equivalent to 1015 PST---within a few minutes of the time at which the thermometer should have been read.

Neiberger[15] has applied the Weather Bureau radiation summaries of Hand[7] to the problem of forecasting maximum temperatures at Chicago and Joliet, Illinois on calm, cloudless days. He recommends the work of Thornthwaite and Holzman[17], of Simpson[20], and of Homen[16] as helpful in evaluating the portion of the insolation applicable to his problems. His method of evaluating the number of calories needed to warm the air to an adiabatic lapse rate eliminates the use of trial and error solutions and is otherwise interesting.

The data can also be applied to the solution of more complicated problems. As an example, let us consider a forecast for the time at which cumulus clouds will form over St. Louis, Mo. on the morning of May 12, 1941: The data available by early morning hours included:

Radiosonde Observation at St. Louis, 01 EST, 5-12-41

Elev	P	T	RH	W
2	998	12	65	5.8
3	980	13	62	6.0
14	855	3	51	2.9

St. Louis Radiosonde Cont'd.

Elev.	P	T	RH	W
22	744	-4	72	2.7
31	698	-7	53	1.8
48	556	-20	43	0.7
50	544	-20	44	0.6
56	496	-24	39	0.6

The minimum temperature was 45° F. The sky was cloudless. No change of air mass or frontal action was expected.

The radiosonde observation is plotted on the adiabatic chart shown in figure 13. The curve is modified to show 45° F as the surface value, with the new inversion drawn at a right angle to the temperature curve. Inspection shows that cumulus clouds may be expected by the time the temperature reaches 62° F. The heat needed to raise the surface temperature to 62° F is 136 calories per square centimeter. Figure 4a, with a scale for 70% use of the maximum insolation, shows that cumulus should be observed by 0915 apparent solar time, or 1015 EST (St. Louis is 90 28' West Longitude). A few cumulus were reported at 1035 EST, with rapidly increasing amounts during the next two hours:

LS	0935 EST	C	○	200/60/47↘7/011	
LS	1035 EST	C	○	196/63/45↓↘11/011/102	10399
LS	1135 EST	C	45⊕	193/65/45↓↘10/⊕010	
LS	1235 EST	C	50⊕	190/66/41↘5/009	

It is hoped that in the future the use of these data can be extended to other problems such as the lake and sea breezes; instability cloudiness, air mass warming, snow melting, rates of evaporation, and perhaps others.

Table 1. A List of Suggested Albedo Values.

Surface	Albedo	Source
Stratus Clouds	0.78	Aldrich [2]
Fresh Fallen Snow	0.783	Zollner [11]
White Paper	0.700	"
White Sandstone	0.237	"
Clay Marl	0.156	"
Moist Earth	0.079	"
Water	0.021	"
Cloudless Sky	0.17	Simpson[20]
0.1 Cloudy	0.22	after Angstrom
0.3 "	0.32	& Aldrich
0.4 "	0.37	"
0.5 "	0.43	"
0.6 "	0.48	"
0.7 "	0.54	"
0.8 "	0.61	"
0.9 "	0.67	"
1.0 "	0.74	"

Water	Angle of Incidence	Albedo	Source[10]
"	0	0.018	Tyndall
"	40	0.022	"
"	60	0.065	"
"	80	0.333	"
"	89.5	0.721	"

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Figure 0. Total Insolation Since Sunrise. 0° Latitude.

Month	Sunrise Time	7	8	9	10	11	12	13	14	15	16	17	18	Total	Sunset Time
		Hour of the day													
Jan.	0600 at all seasons	15	57	125	213	316	426	536	638	726	794	836	851	851	[illegible] seasons
Feb.		15	59	129	221	327	441	555	661	753	873	867	882	882	
Mar.		17	60	131	224	332	448	564	671	764	835	880	896	896	
Apr.		15	58	127	218	323	435	544	652	743	812	855	870	870	
May		14	55	120	205	304	410	517	615	700	765	806	820	820	
June		14	53	116	198	293	396	498	593	675	738	778	791	791	
July		14	53	117	199	295	398	501	597	679	742	782	795	795	
Aug.		14	56	123	209	310	419	527	628	715	781	823	837	837	
Sept.		15	59	128	219	324	437	550	656	746	816	860	875	875	
Oct.		15	59	119	221	327	441	555	662	753	823	867	882	882	
Nov.		15	58	126	215	318	429	540	644	733	801	844	858	858	
Dec.		14	56	123	210	311	420	528	629	716	783	825	839	839	

Unit: Calories per Cm^2

Figure 1. Total Insolation Since Sunrise. 10° North Latitude.

Month	Sunrise Time	Hour of the day: 6	7	8	9	10	11	12	13	14	15	16	17	18	Total	Sunset Time
Jan.	0616		8	42	101	180	274	374	475	569	648	707	741		749	1744
Feb.	0610		11	49	113	199	299	407	514	614	700	764	802		813	1730
Mar.	0602		14	58	127	217	323	436	549	656	746	815	858		872	1758
Apr.	0553	0	18	64	135	228	334	448	562	668	761	832	878	896	896	1807
May	0546	1	21	67	138	228	331	442	553	656	746	817	864	884	885	1814
June	0543	2	23	69	138	227	328	436	544	646	733	804	849	870	872	1817
July	0544	1	21	68	137	226	327	436	545	646	735	804	850	871	872	1816
Aug.	0550	0	19	65	136	226	330	442	553	658	748	818	864	883	884	1810
Sept.	0558	0	16	60	129	220	325	437	550	655	745	815	859	874	874	1802
Oct.	0606		12	52	119	206	308	417	527	628	716	782	822		834	1754
Nov.	0614		9	44	105	186	282	384	487	582	663	724	760		769	1746
Dec.	0617		7	40	98	175	266	365	464	556	633	690	724		730	1742

Units: Calories per Cm.²

Figure 2. Total Insolation Since Sunrise. 20° North Latitude.

Month	Sunrise Time	6	7	8	9	10	11	12	13	14	15	16	17	18	Total	Sunset Time
Jan.	0633		3	28	76	144	226	314	402	485	553	601	626		628	1727
Feb.	0620		6	38	95	171	262	356	449	540	616	673	705		711	1740
Mar.	0603		13	53	118	204	303	411	518	617	702	768	808		821	1757
Apr.	0546	1	21	68	140	231	337	449	561	667	757	829	876	896	897	1814
May	0532	3	28	79	153	245	351	463	575	681	773	846	897	922	925	1828
June	0524	5	32	85	159	251	355	466	578	682	775	848	900	928	932	1836
July	0527	4	31	82	156	247	352	462	573	678	769	843	894	921	925	1833
Aug.	0539	2	25	73	145	236	341	452	564	668	759	831	880	903	904	182[illegible]
Sept.	0555	0	16	60	127	214	316	424	533	634	721	789	832	848	848	1805
Oct.	0612		9	45	105	185	279	380	482	576	656	716	752		761	1748
Nov.	0628		4	31	82	153	237	328	420	504	575	626	653		657	1732
Dec.	0636		2	25	72	138	217	303	389	468	533	580	603		605	1724

Unit: Calories per Cm^2

Figure 3. Total Insolation Since Sunrise. 30° North Latitude.

Month	Sunrise Time	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total	Sunset Time
Jan.	0652		0	15	52	106	173	247	320	387	442	478	493			493	1708
Feb.	0631		3	28	75	140	219	305	390	468	533	582	606			609	1729
Mar.	0605		11	48	107	184	276	374	472	564	641	701	737			742	[illegible]
Apr.	0538	2	24	71	141	224	329	436	543	643	731	800	847	870		872	[illegible]
May	0515	7	37	95	169	261	365	475	585	689	781	855	913	943		950	[illegible]
June	0502	11	45	101	178	271	375	486	596	702	793	870	925	961		972	[illegible]
July	0507	9	41	97	172	264	367	477	587	691	783	858	914	945		954	[illegible]
Aug.	0526	4	30	80	152	241	342	450	558	659	748	819	870	896		900	1834
Sept.	0553	0	16	57	121	202	297	398	500	595	676	739	780	796		796	[illegible]
Oct.	0619		6	36	88	158	242	333	423	507	577	630	659			665	[illegible]
Nov.	0645		1	19	59	117	188	265	343	413	471	512	530			531	[illegible]
Dec.	0657		0	13	47	99	163	233	304	368	420	464	467			467	[illegible]

Unit: Calories per Cm²

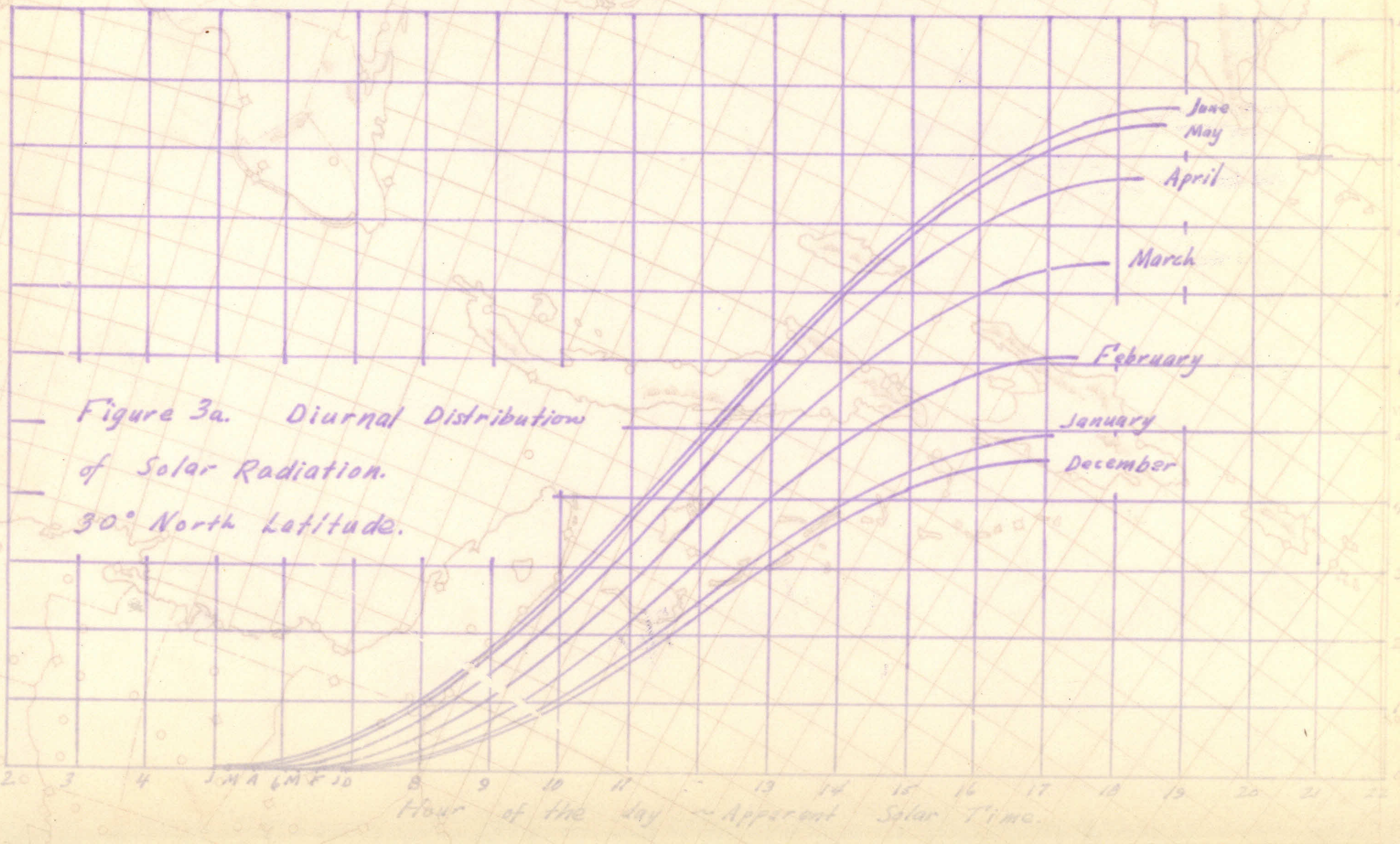

Figure 3a. Diurnal Distribution of Solar Radiation. 30° North Latitude.

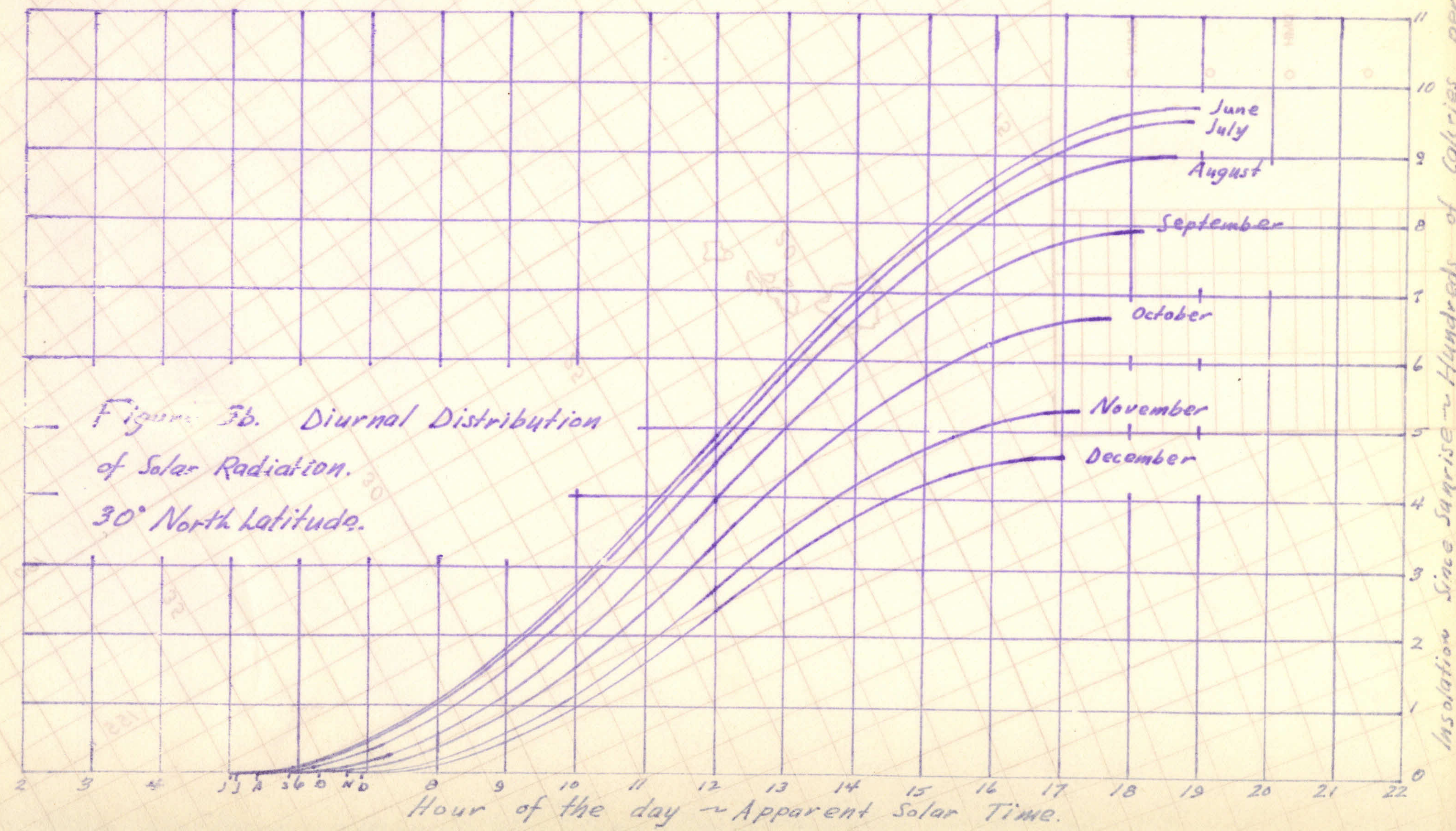
Figure 3b. Diurnal Distribution
of Solar Radiation.
30° North Latitude.
June
July
August
September
October
November
December
Insolation Since Sunrise ~ Hundreds of Calories per Cm²
Hour of the day ~ Apparent Solar Time.
0
1
2
3
4
5
6
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8
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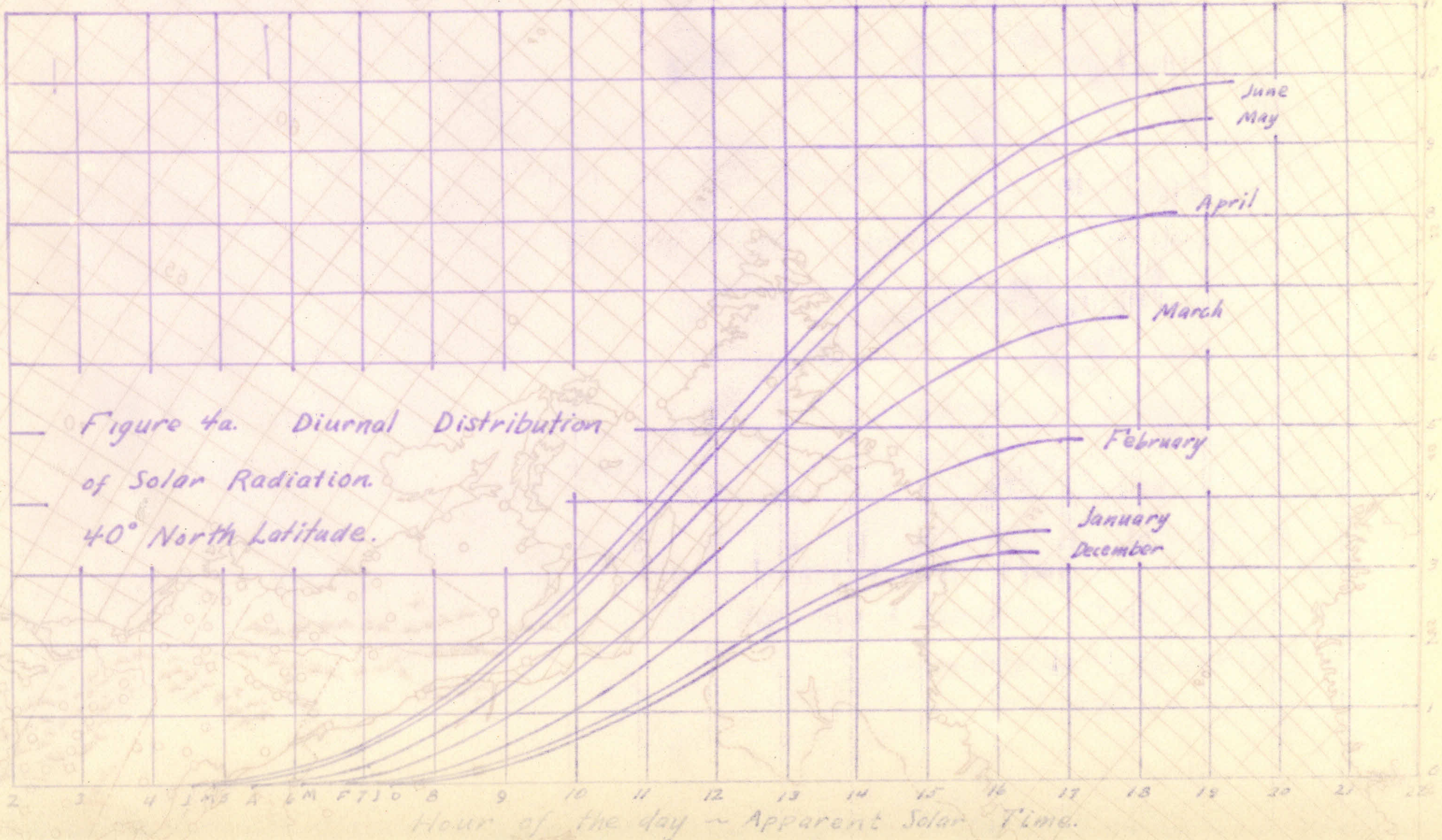
22

Figure 4. Total Insolation Since Sunrise. 40° North Latitude.

Month	Sunrise	Hour of the day: 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total	Sunset Time
Jan.	0717				5	29	68	119	175	232	283	322	346				351	1643
Feb.	0645			1	17	53	106	170	241	311	375	428	464	480			482	1715
Mar.	0608			9	41	93	161	241	327	413	493	561	613	645			654	1752
Apr.	0527		3	25	69	133	213	304	401	498	588	667	737	776	798		801	1833
May	0454	0	13	47	102	175	264	363	467	571	670	759	832	887	921	934	934	1906
June	0435	2	20	59	118	194	286	387	494	600	703	793	870	930	969	986	989	1925
July	0442	1	17	54	111	186	276	376	482	586	687	777	851	910	946	962	963	1918
Aug.	0511		7	36	86	155	239	334	435	536	632	716	786	835	864		872	1849
Sept.	0549		0	16	53	111	184	269	360	457	576	609	667	704	720		720	1811
Oct.	0628			3	23	69	128	199	276	352	423	482	524	548			551	1732
Nov.	0706				9	36	80	135	196	256	311	355	382				391	1654
Dec.	0725				4	25	61	108	162	216	264	300	321				324	1635

Unit: Calories per Cm^2


June
May
April
March
February
January
December
Figure 4a. Diurnal Distribution
of Solar Radiation.
40° North Latitude.
Hour of the day ~ Apparent Solar Time.

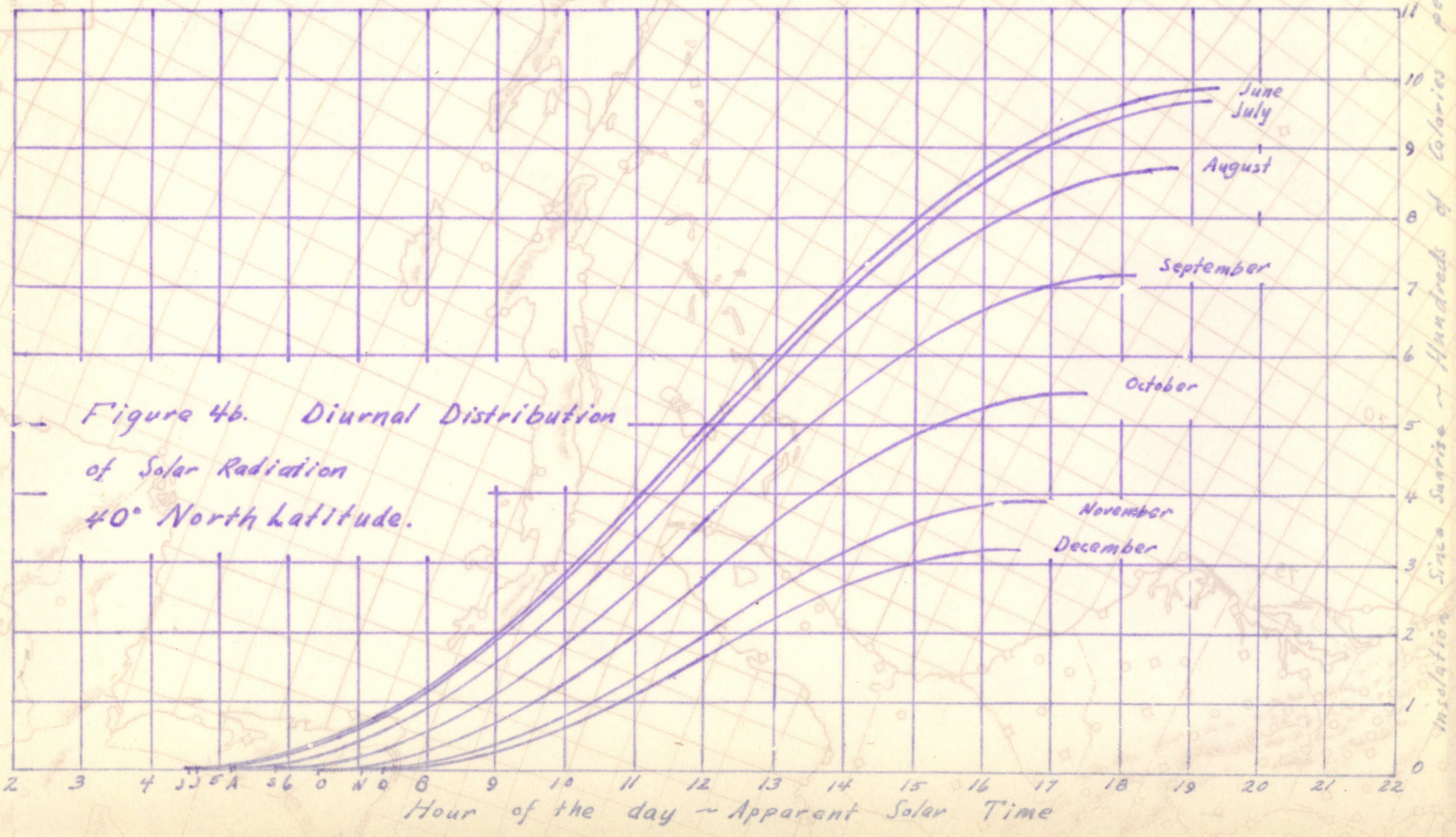


Figure 4b. Diurnal Distribution of Solar Radiation 40° North Latitude.

Figure 5. Total Insolation Since Sunrise. 50° North Latitude.

Month	Sunrise Time	Hour of The day																	Total
		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Jan.	0751					0	10	33	66	103	140	173	197	207					20[illegible]
Feb.	0705					8	32	70	118	171	224	272	310	334					34[illegible]
Mar.	0611				8	35	79	137	204	277	350	417	475	519	546				55[illegible]
Apr.	0513			6	30	73	132	204	287	374	461	542	614	674	717	741			746
May	0425		3	22	59	113	183	265	356	452	548	639	723	792	845	882	901		904
June	0356	0	9	34	77	136	211	298	392	492	592	687	773	848	906	950	975	984	984
July	0407		6	29	69	127	199	283	377	472	572	665	758	822	879	920	942		94[illegible]
Aug.	0450		0	12	43	91	155	232	318	409	500	586	663	727	775	805	807		817
Sept.	0545			1	15	48	98	161	233	311	389	462	525	594	607	623			623
Oct.	0640				1	16	48	94	158	210	270	326	372	404	419				420
Nov.	0735					2	16	45	82	124	167	204	232	247					247
Dec.	0803						7	26	55	89	123	152	172						[illegible]

Unit: calories per [illegible]

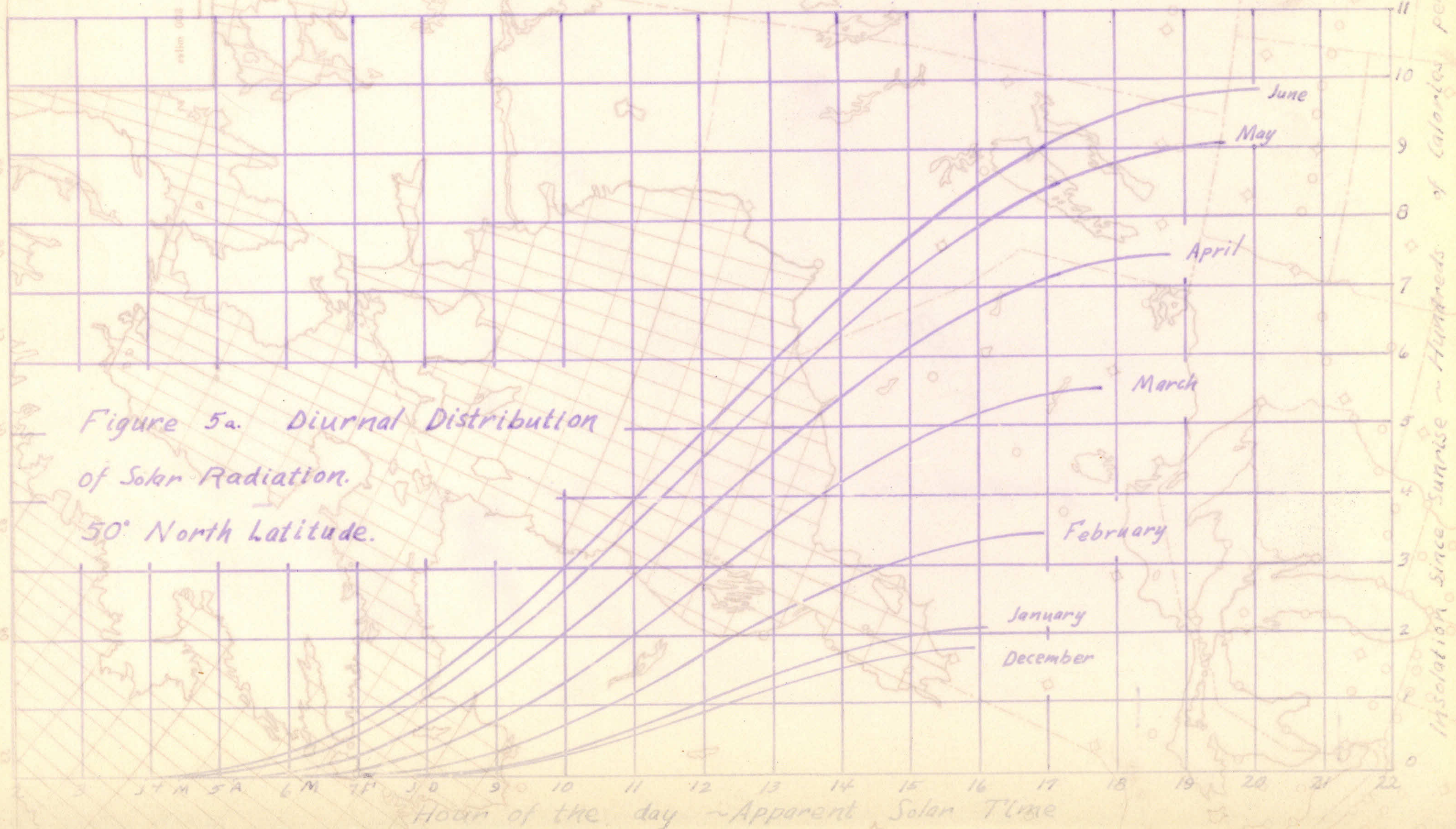


Figure 5a. Diurnal Distribution
of Solar Radiation.
50° North Latitude.
June
May
April
March
February
January
December
Insolation since Sunrise ~ Hundreds of Calories per Cm.
Hour of the day ~ Apparent Solar Time
0
1
2
3
4
5
6
7
8
9
10
11
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

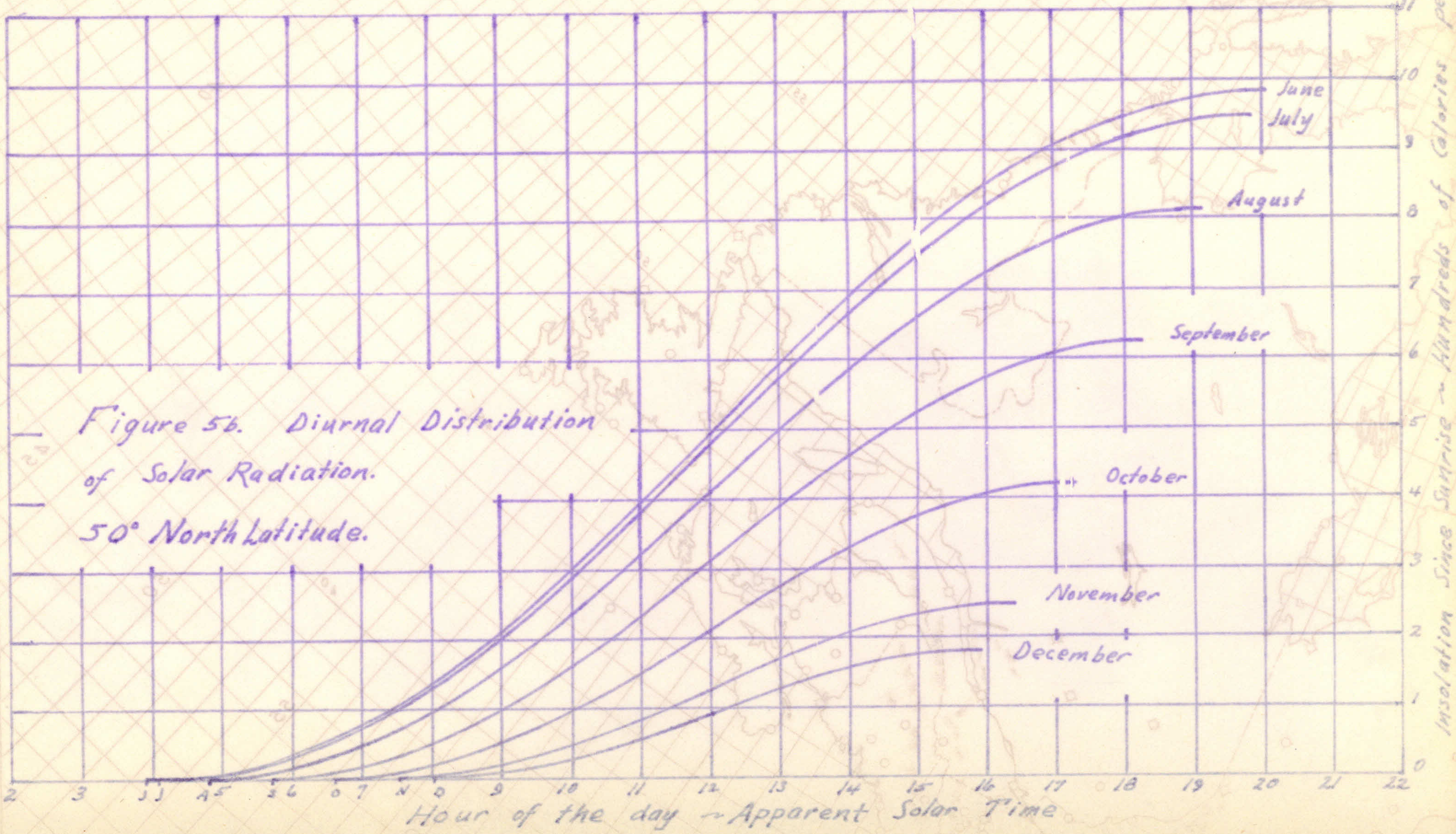


Figure 5b. Diurnal Distribution of Solar Radiation. 50° North Latitude.

Figure 6. Total Insolation Since Sunrise. 60° North Latitude.

Month	Sunrise Time	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Total	Sunset Time
Jan	0851							0	7	20	38	55	69	75							75	1507
Feb.	0736						1	13	35	65	99	132	162	184	196						197	1624
Mar.	[illegible]					4	22	54	96	146	200	254	303	346	377	395					399	1744
Apr.	0452			0	10	34	72	123	185	254	327	400	469	530	581	620	644	654			654	[illegible]
May	0336		1	12	36	75	127	191	265	346	431	515	596	670	734	786	825	849	860		861	2044
June	0247	0	7	26	58	103	161	231	310	396	486	575	661	742	810	870	914	946	966	972	973	2113
July	0307		4	20	49	91	147	214	291	375	462	549	633	710	777	833	876	905	920		924	2053
Aug.	0416			4	20	52	97	154	221	296	374	452	536	595	651	697	728	745			749	1947
Sept.	0538				1	14	41	82	133	191	253	315	374	424	465	492	505				506	[illegible]
Oct.	0659					0	7	28	59	97	140	182	220	251	272	279					279	[illegible]
Nov.	0823							2	14	33	56	78	97	109							111	1622
Dec.	0907								3	13	26	40	50								53	[illegible]

Unit: Calories per Cm^2

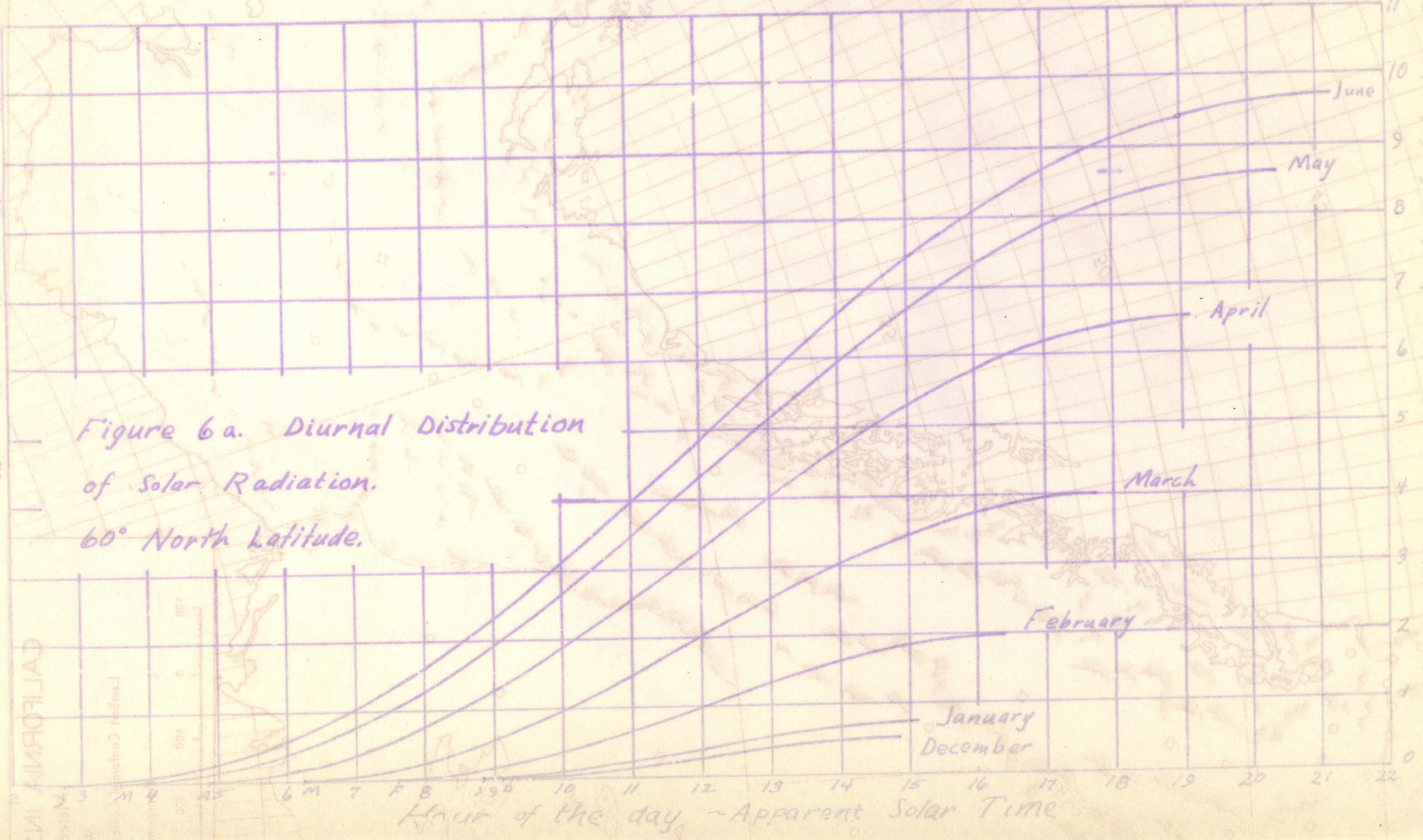


Figure 6 a. Diurnal Distribution of Solar Radiation. 60° North Latitude.

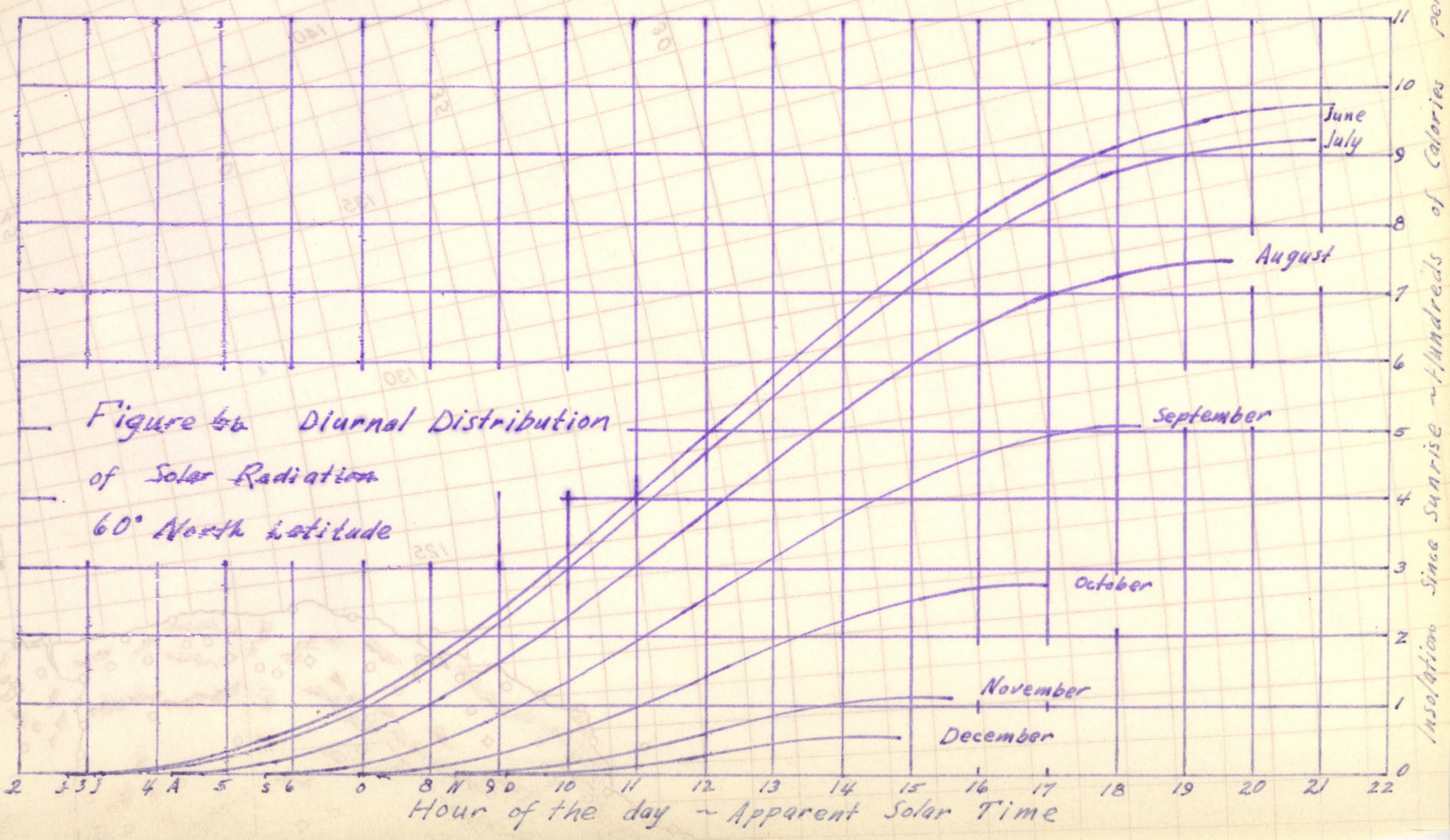


Figure ~~6a~~ Diurnal Distribution
of ~~Solar Radiation~~
60° ~~North Latitude~~
June
July
August
September
October
November
December
Hour of the day ~ Apparent Solar Time
Insolation since sunrise ~ Hundreds of Calories per Cm²

Figure 7. Total Insolation Since Sunrise. 70° North Latitude.

Month	Sunrise Time	Hour of the day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total
Jan.		None																							
Feb.	0840									0	6	17	31	45	55	61									62
Mar.	0626							2	13	32	60	92	127	162	195	222	242	253							255
Apr.	0409					3	16	40	73	114	163	217	274	330	384	433	474	508	531	544					548
May	0125		0	6	18	38	67	106	154	211	274	341	412	482	550	613	670	717	756	786	806	818	824		824
June	*	7	16	30	50	79	116	162	217	281	350	424	501	577	651	721	784	840	886	923	950	971	985	994	1001
July	*	4	10	20	37	62	97	140	192	253	320	391	465	539	611	678	738	791	834	868	893	911	921	927	931
Aug.	0304				2	14	35	66	106	155	211	272	335	398	458	514	563	604	634	656	667				669
Sept.	0524						2	13	34	64	101	143	188	232	275	312	341	362	374						375
Oct.	0735								1	9	24	45	68	91	111	127	135								136
Nov.	1032											1	3	5											6
Dec.		None																							

* No sunset.

Unit: Calories per Cm.²

Figure 8. Total Insolation Since Sunrise. 80° North Latitude.

Month	Sunrise Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Total	Sunset Time
Jan.			None																							
Feb.			None																							
Mar.	0653							0	3	11	22	36	52	67	81	93	100	104							104	[illegible]
Apr.	0106		1	4	11	22	39	60	87	118	152	189	228	267	304	338	369	396	417	433	444	451	454		455	[illegible]
May.	*	17	36	57	81	110	141	181	224	271	321	373	427	481	533	583	630	673	712	745	773	797	820	837	854	*
June.	*	26	53	83	115	152	194	239	291	345	403	463	525	586	646	704	758	810	856	897	934	966	996	1024	1050	*
July	*	23	47	73	103	137	175	219	265	317	372	429	488	546	604	659	710	758	801	839	873	903	929	953	976	*
Aug.	*	9	18	31	46	66	91	121	156	195	237	282	328	374	419	462	501	535	565	590	610	626	638	648	656	*
Sept.	0446					0	4	13	27	45	67	92	118	144	169	191	209	223	232	236					236	[illegible]
Oct.	0945										1	3	6	9	11										13	[illegible]
Nov.			None																							
Dec.			None																							

* No Sunset.

Unit: Calories per Cm.²

Figure 9. Total Insolation Since Sunrise. 90° North Latitude

Month	Sunrise Time	Hour of the day																								Sunset Time
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Jan.		None																								
Feb.		None																								
Mar.		None																								
Apr.	*	19	38	58	77	96	115	135	154	173	192	212	231	250	269	278	308	327	346	355	384	404	423	442	461	*
May	*	36	73	109	146	182	219	255	292	328	364	400	437	474	510	547	583	619	656	692	729	765	802	838	875	*
June	*	44	89	134	178	222	267	312	356	400	445	490	534	578	623	668	712	756	801	846	890	934	978	1023	1068	*
July	*	41	83	124	165	206	248	289	330	372	413	454	495	537	578	619	660	702	743	784	826	867	908	949	990	*
Aug.	*	28	56	83	111	139	167	194	222	250	278	306	333	361	389	417	444	472	500	528	556	583	611	639	667	*
Sept.	*	6	13	19	26	32	39	45	51	58	64	71	77	84	90	96	103	109	116	122	129	135	141	148	154	*
Oct.		None																								
Nov.		None																								
Dec.		None																								

* No Sunset.

Unit: Calories per Cm^2

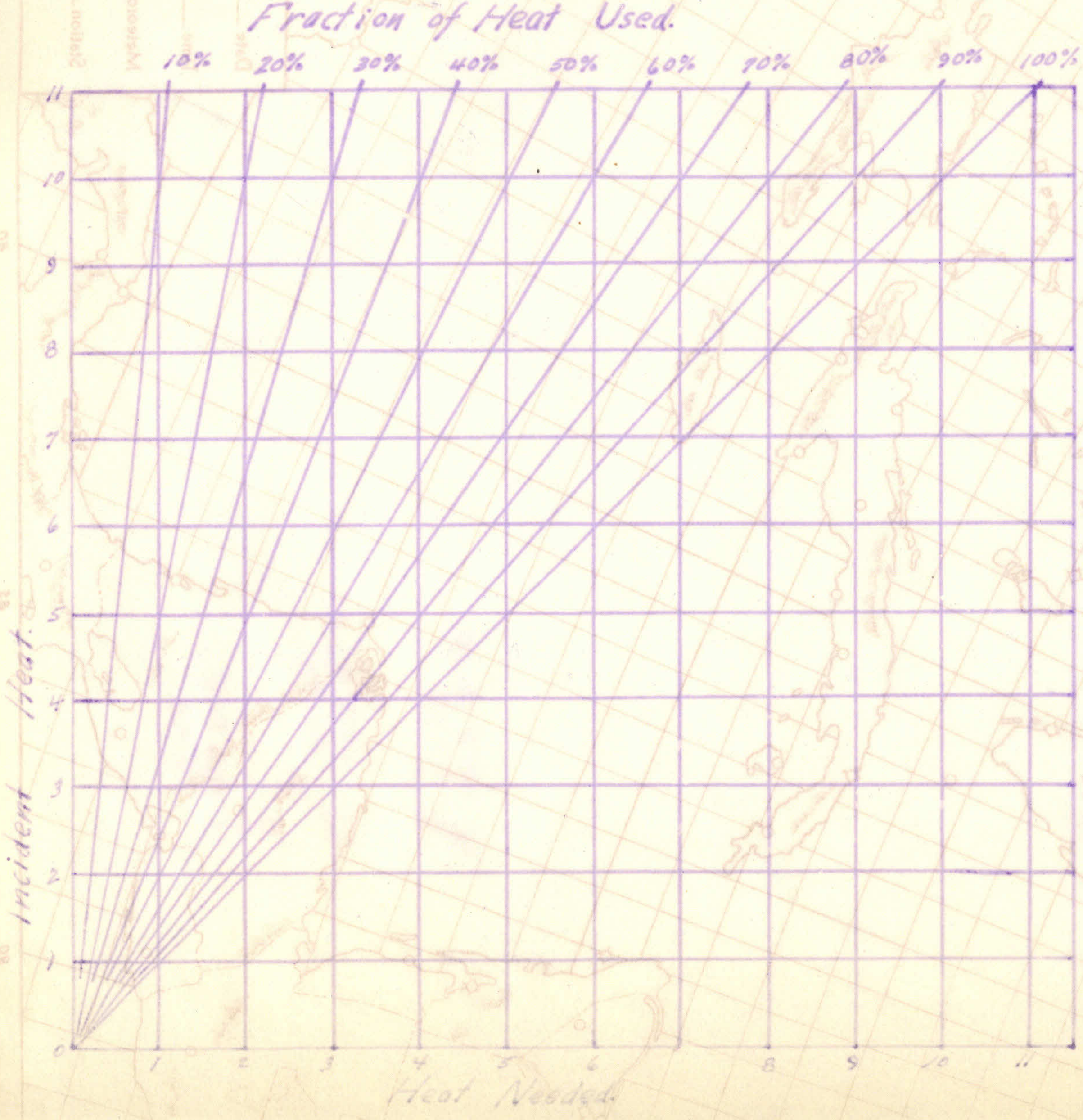


Figure 10. Scale to be used when less than 100% of the incident Insolation is applied to the problem at hand.

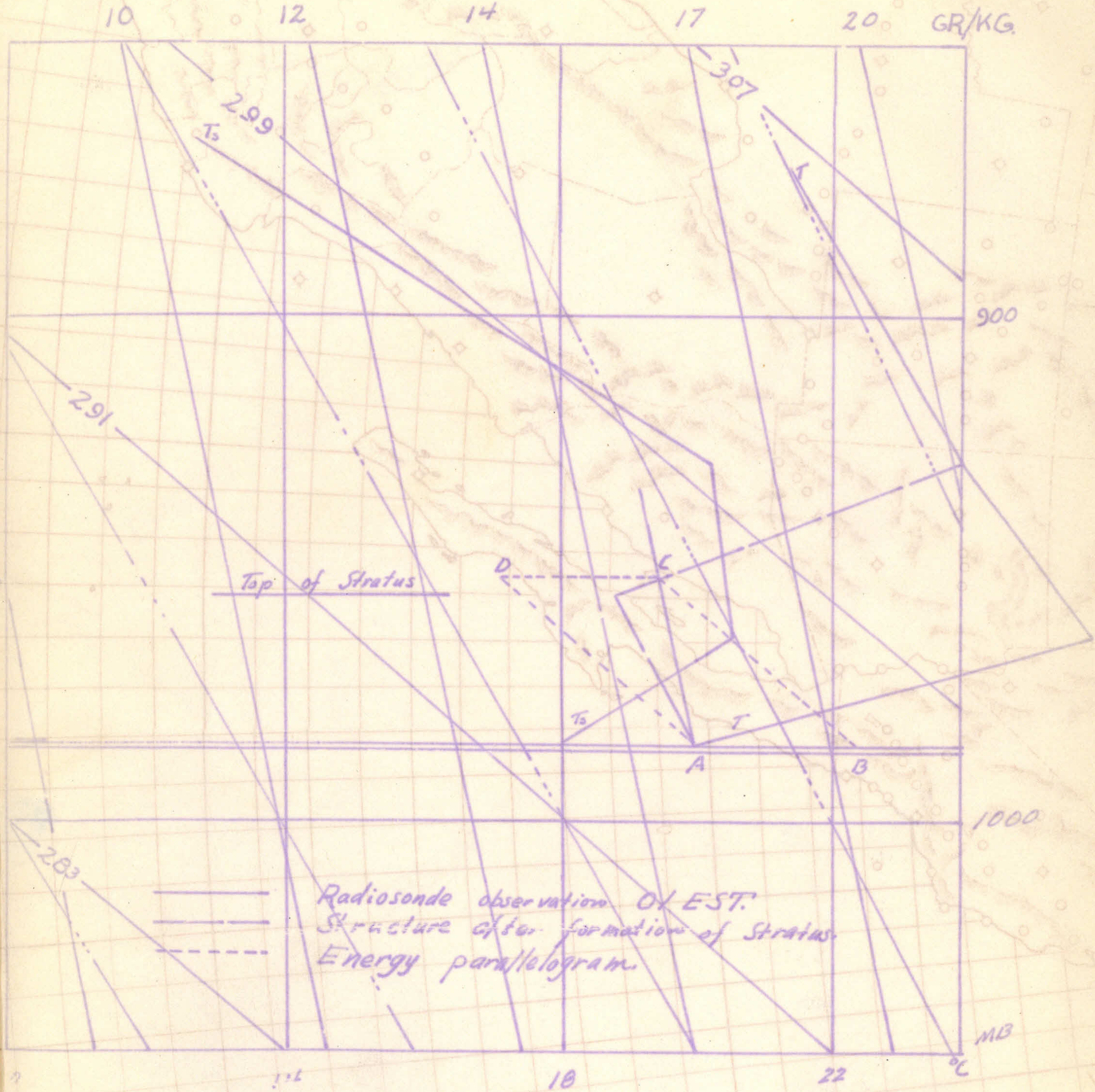


Figure 11. San Antonio, Texas, May 7, 1941.

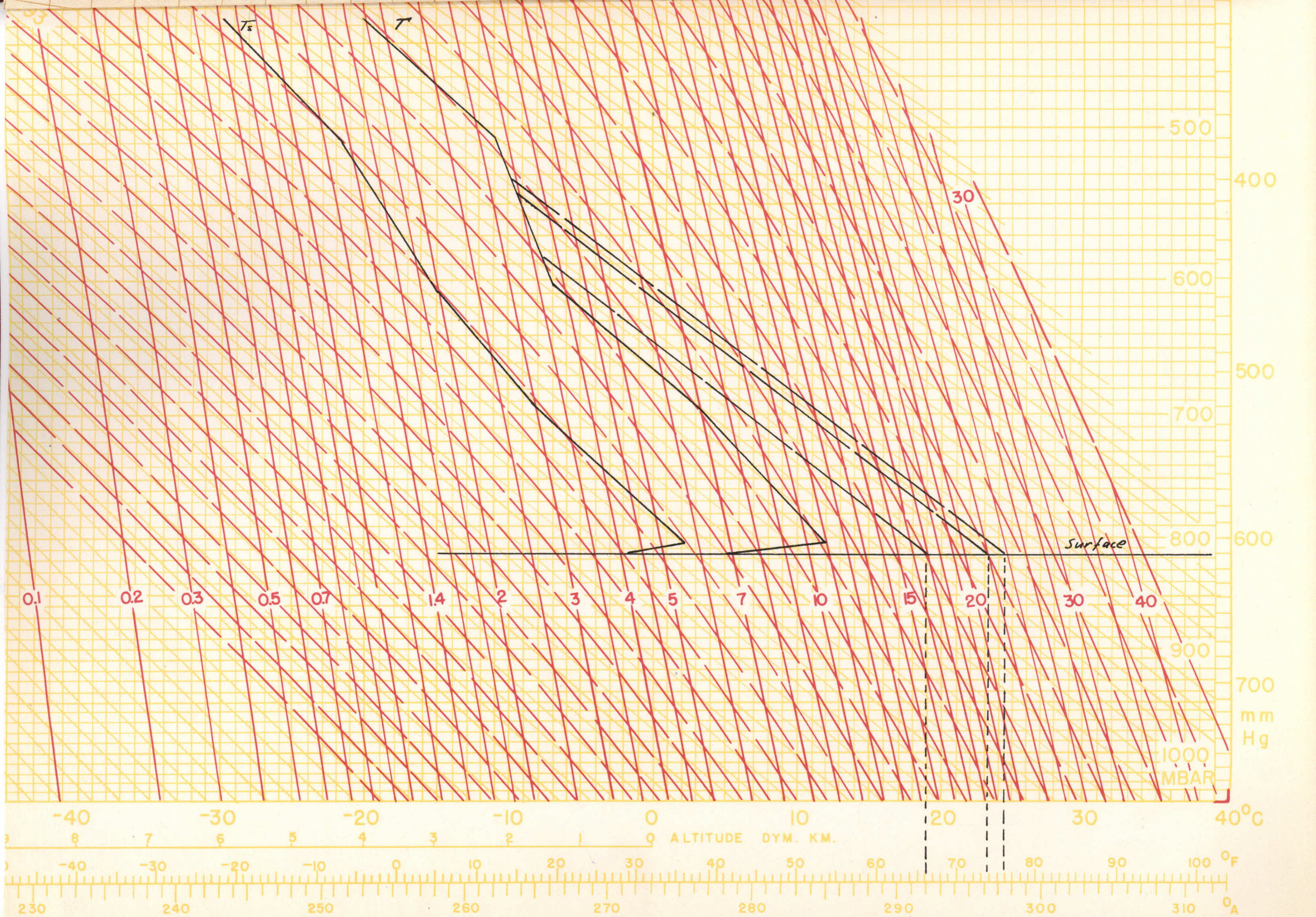


Figure 12. Ely, Nevada, May 16, 1941.

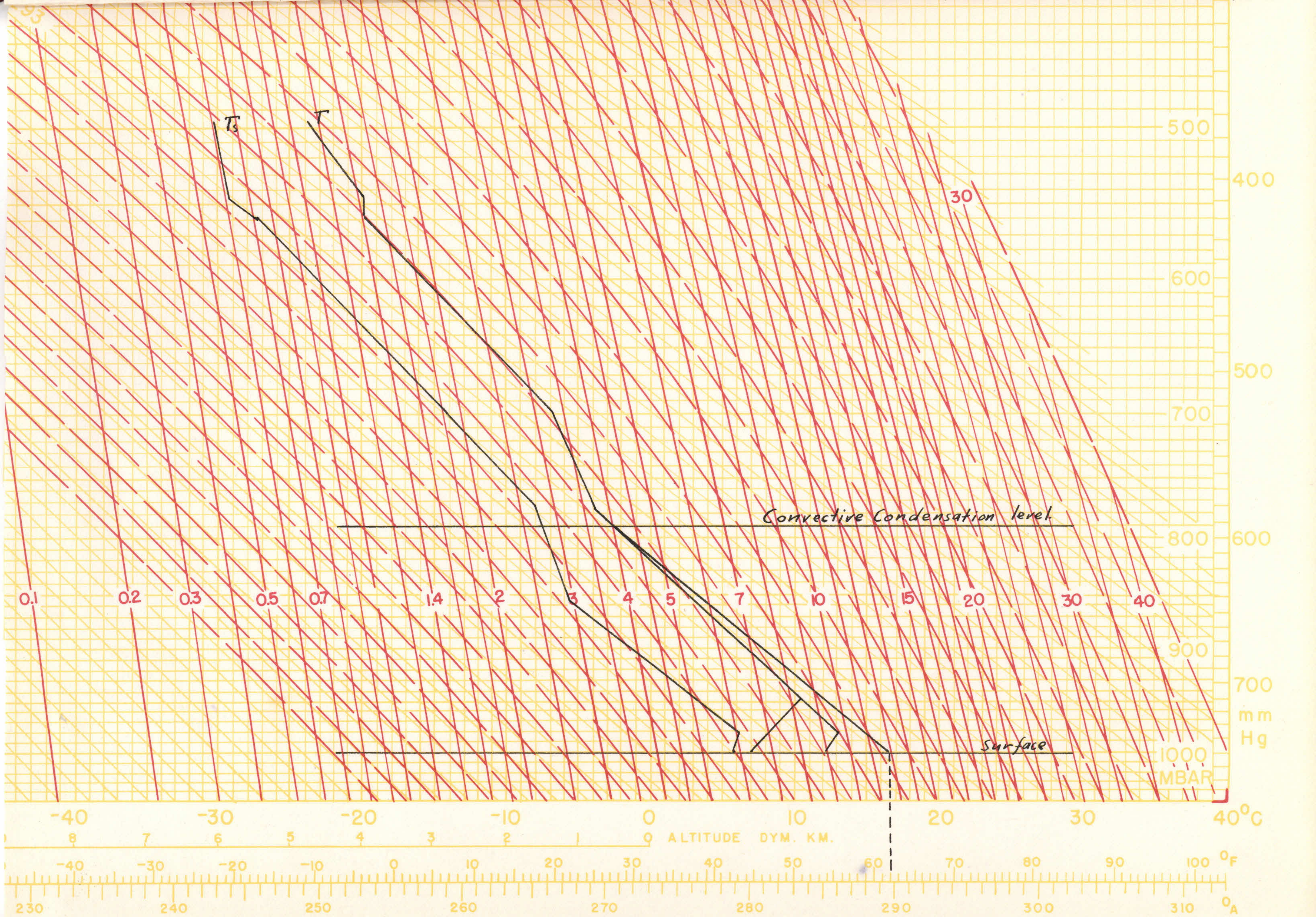


Figure 13. St. Louis, Mo, May 12, 1941.

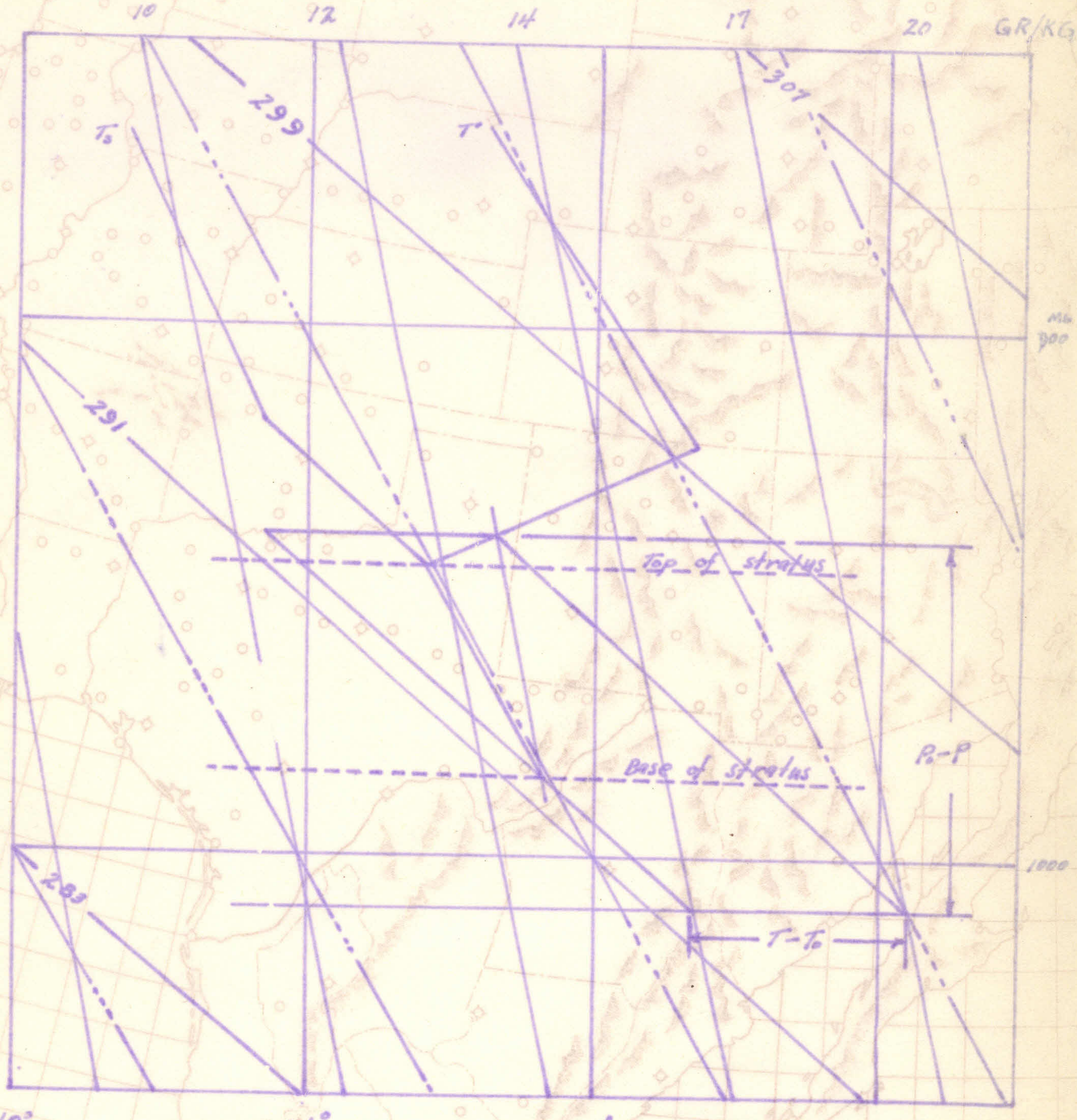


Figure 14. Method of Evaluating Heat needed to dissipate stratus.

Appendix

If a small amount of heat dQ be added to a parcel of air, the temperature increase dT produced in the air will be given by the equation:

$$dQ = c_p M dT$$

where: c_p is the specific heat of the air at constant pressure.

M is the mass of the air.

If the parcel of air has a cross section area of one square centimeter its mass will be given by:

$$M = \frac{P_0 - P}{g}$$

where P is the pressure at the top of the column, and P_0 at the base.

g is the acceleration due to gravity.

Our equation then becomes:

$$dQ = \frac{c_p}{g}(P_0 - P)\, dT \quad \text{calories per cm}^2$$

or if $P_0 - P$ be in millibars, $g = 980$ cm./sec.², and $c_p = .2396$:

$$dQ = .244(P_0 - P)\, dT \text{; and by integrating:}$$

$$Q - Q_0 = .244(P_0 - P)(T - T_0) \quad \text{calories per cm}^2$$

where T_0 and Q_0 refer to the air before the addition of heat, and T and Q refer to it afterward.

The quantity $Q - Q_0$ is the amount of heat we want to know, and can be found if the values of P, P_0, T and T_0 are known. In solving a stratus dissipation problem, the difference between the minimum and critical temperatures is multiplied by the depth of the layer as measured in millibars and by 0.244 to obtain the value needed. The evaluation is exact and takes but a moment on a slide rule.