Bound File - Prediction of Afternoon Effect   L. P. Woollard

Office of Scientific Research and Development
National Defense Research Committee
Division C - Section 4

PRELIMINARY REPORT ON THE PREDICTION OF "AFTERNOON EFFECT"

by
C. O'D. Iselin and A. H. Woodcock
Woods Hole Oceanographic Institution
Contract OEMsr-31

OSRD No.
Section No. C4-sr31-137
Copy No. 99

July 25, 1942

Copies No. 1 through 24 - Executive Secretary, N.D.R.C.
Copy No. 25 - Chairman, Division C
Copies No. 26 through 30 - Coordinator of Research and Development
Copy No. 31 - Captain W. D. Baker
Copy No. 32 - Director, New London laboratory
Copy No. 33 - Director, San Diego laboratory
Copy No. 34 - Director, Harvard laboratory
Copy No. 35 - Lieut. Commander R. Bennett
Copy No. 36 - Dr. R. H. Fleming
Copy No. 37 - Dr. Lyman Spitzer, Jr.
Copies No. 38 through 45 - Section C-4 files
Copies No. 46 through 65 - W.H.O.I. files

PRELIMINARY REPORT ON THE PREDICTION OF "AFTERNOON EFFECT".

by
C. O'D. Iselin and A. H. Woodcock

Woods Hole Oceanographic Institution July 25, 1942

Introduction

With moderate or light winds and a clear sky the diurnal heating which occurs near the sea surface can cause a serious reduction in the range of submarine detection, especially on shallow targets. This has usually been called the "afternoon effect", although as will be noticed below the ranges often remain short long after sun down. The heating of surface waters which causes such sharp downward refraction can of course be noted on a bathythermograph record, provided pen vibration does not confuse the upper part of the trace. Unfortunately it is the upper 20 or 30 feet of a bathythermograph curve which in the case of ships moving faster than 12 knots is often somewhat difficult to read with sufficient certainty. Moreover, in planning a days operations it is clearly desirable to know in advance how much reduction in range may be expected from diurnal warming.

Unfortunately it has turned out that five, more or less independent variables are involved. Listed in the order of their importance these are as follows: the altitude of the sun, the degree of cloud coverage, the strength of the wind, the difference in temperature between air and water, and the humidity of the air.

It was at first thought that wind and cloud observations alone would be sufficient in most cases for a rough prediction of the seriousness of diurnal warming to echo ranging conditions. Thus it has been previously reported that with winds of force 4 or greater it can be expected that turbulence will prevent thermal stability from developing at depths critical to sound ranging, while with lighter winds ranges will be more or less reduced in the afternoon, except during cloudy weather. But the problem is considerably more complex than this and such simplification is not always justified.

Observational program and methods of analysis

Between March 27 and April 26, 1942 the "Atlantis" carried out a 25 day study of solar heating in the upper 70 fathoms in the central part of the Gulf of Mexico. Hourly bathythermograph lowerings were made during all of this period and detailed meteorological records were kept. The wind drift of the vessel was measured and occasional changes in position were made in order to remain in the same water mass. During this time of year the Central Sea area of the Gulf is practically free of currents.

In addition to this very complete data it has been found possible to use a few of the "Atlantis" observations from other areas and from other times of year. This latter material has had to be used cautiously, for most of the time the vessel was cruising and therefore horizontal variations might affect the results.

At the outset of the investigation a thorough review of the literature on the transfer of heat and water vapor across the sea surface was made by Dr. R. B. Montgomery. A copy of this manuscript is attached to this report. In addition, Hand's solar and sky radiation measurements have been used in computing the heat exchange across the sea surface. In general the results of the "Atlantis" observations corroborate Montgomery's tables and equations in so far as orders of magnitude are concerned, but it is obvious that much additional work is needed before more precise calculations will be possible.

Through the cooperation of the meteorological department of the University of Chicago additional observations are now in progress in Lake Michigan.

Results

It was found that in general there was no surface heating significant to sound ranging unless the incoming solar radiation exceeded heat losses during the day by about 200 to 300 calories per square centimeter per day*, depending on the strength of the wind.

As an example of the work done during this study, a typical day's records (for April 3rd) are shown in Table I. The relative importance under these conditions of evaporation, conduction, and nocturnal radiation is readily seen by examining columns A, B and C. During this particular day the heating was sufficient to reduce a morning range of at least 4500 yards to an assured range of only 500 yards by 1800 o'clock (see Fig. 1). This series of ray diagrams shows the effect of this days heating upon sound conditions from 1000 to 2400 o'clock. Shortly after midnight the water again became isothermal to 60 fathoms and the assured range returned to 4500 yards.

Table II is a tabulation of the heat exchange across the surface of the sea during the period 0700 to 1700 o'clock for each day that suitable records are available. Column 5 is arranged in order of increasing values and it is evident that there is in general a fairly clear correlation between an increasing positive heat balance and an increasing reduction of range (column 6). The principal exceptions to this general rule are January 29, 1941,

---

* "day" meaning the hours 07 to 17 o'clock inclusive.

and April 4, 1942. In the former case the calm conditions allowed a concentration of heating near the surface, while on April 4th the brisk winds distributed the greater heat through an exceptionally deep layer, reducing the gradient. The ranges in Table II were computed for a projector depth of 15 feet. The assured ranges would be somewhat less for a 9 foot projector, and greater for one at 25 feet.

In Figure 2 an attempt has been made to allow for the variations in wind strength on the downward penetration of heat absorbed near the surface. The residual heat (recorded in column 6 of Table II has been plotted against the negative temperature gradients observed in the afternoon in the upper 30 feet. The wind forces have been entered beside each of the 23 dots on the diagram. Finally, lines of equal wind force have been fitted to these data by inspection. It will be seen that if the heat balance and the average wind force have been observed, one might expect from Figure 2 to know the negative temperature gradients in the surface layer with sufficient accuracy for the purposes of range estimates.

For Figure 2 to be useful for range prediction it is of course necessary for the morning values of residual heat and winds to have a correlation with the eventual negative thermal gradients in the surface layer. This can be expected on the basis that weather at sea usually changes gradually. In other words, the morning weather is in general a good indication of what can be expected in the afternoon. A scale for morning observations as well as for the whole day will be found on the diagram.

When the heat exchange is computed from hourly observations made between 0800 and 1100 o'clock on each of the 24 days listed on Table II, it is found that with only two exceptions the afternoon temperature gradients can be read off Figure 2 with just as useful accuracy as when the whole day's heat balance is known. On these exceptional days overcast skies in the morning changed to clear in the afternoon so that the thermal gradients were somewhat greater than could be expected on the basis of the morning observations, but with a little weather sense allowance can be made for such cases.

Before an observer can use Figure 2 and get an approximation of the thermal stability to be expected near the surface following a given morning's heating, he must fill out such a table as Table III. Here the morning observations for April 4, 1942 have been entered. Seven of the columns (a, b, c, f, k, l and s) contain the basic observational data. These should be made as recommended in the "Instructions to Marine Meteorological Observers" published by the U.S. Weather Bureau in January 1938. The remaining columns in Table III are filled in as follows:

Column d: The difference between columns b and c.
Column e: Found in Table IV from the values in columns c and d.
Column g: The difference between columns f and c.
Column h: Found in Table V.

Column i: Found in Table VI from the values in columns c and e.
Column j: The difference between columns h and i.
Column m: Found from the values in columns f and i, using Figure 3.
Column n: Found from Figure 3.
Column o: Column m minus column n.
Column p: Multiply column j by the factor found in Table VII.
Column q: Multiply column g by the factor found in Table VIII.
Column r: The sum of columns o, p and q.
Column t: Found from column s and Figure 4.
Column u: A 7% reduction of the values in column t for each unit recorded in column l.
Column v: Column t minus column u.
Column w: Column v minus column r.

The sum of the values arrived at in column w, along with the appropriate average wind force (column h), may now be used in Figure 2 to get an approximation of the negative thermal gradient to be expected during the afternoon. To transform the expected negative thermal gradient to the probable assured range, such a table as Table 2 in the "Instructions for Bathythermograph Observers, Part II", can be used. This table is reproduced here as Table IX. Somewhat more exact values for a projector at 15 feet can be found by using Figure 5.

Various attempts have been made to shorten the labor involved in this rather lengthy process, but so far each simplification has resulted in some loss of accuracy. The best short cut method so far devised involves the use of Figure 6. This consists of a nomogram where estimates of the residual heat are obtained from the average sky coverage and the average difference in temperature between air and water during the morning. The heat value thus obtained is then used, along with the average wind force for the 4 morning observations, in Figure 2 to find the probable negative temperature gradient, which in turn can be transformed to estimated assured range for the afternoon by the use of Table IX or Figure 5.

It is obvious that in Figure 2 small errors in the wind force estimates can greatly influence the results. Moreover, wind force is about the most difficult meteorological factor to measure accurately at sea. Until these methods can be more fully tested and more observations have been obtained, it cannot be known whether or not the use of an anemometer would improve the results.

Figure 2 was made up from observations and heat exchange calculations secured on days when there was always a heat loss from the water surface by evaporation. Little is known of the rate of gain of heat due to condensation of water vapor on a colder sea surface. However, on one day during which condensation conditions obtained, the calculated heat values give a close approximation of the measured negative thermal gradient when Figure 2 is used along with the average wind force for the day.

It is interesting to note that diurnal heating superimposed upon a deep mixed layer has about the same effect in reducing the assured range as the same amount of heating upon a shallow mixed layer. Figures 7, 8 and 9 demonstrate this point and are also helpful as illustrations of the effect of increasing thermal stability in the upper 30 feet of the water-column. It can be seen from these diagrams, for example, that with a negative thermal gradient of .5°F, a target picked up at 1500 yards is probably below a depth of 50 feet, while at 2000 yards it is probably below 100 feet. A gradient of 1°F per 30 feet would mean that a target picked up at 1000 yards was below 50 feet and that a target at 1500 yards was below 100 feet.

In this report most of the tables and figures relating to heat exchange are simplifications or approximations and hence should not be regarded as exact statements.

Summary and conclusions

1. Twenty four selected series of meteorological observations and bathythermograph records have been analyzed with the object of finding a method of predicting the loss of assured range resulting from diurnal warming.

2. The number of variables which combine in determining the vertical temperature gradients near the surface are too great to permit any simple solution to this problem. Moreover, it is also clear that the number of available observations is too small to warrant a statistical study.

3. Methods are given for computing the heat exchange at the sea surface. On the assumption that the morning weather is a reliable indication of that which will be encountered during the remainder of the day, it is possible to estimate the afternoon's maximum thermal stability by means of Figure 2, and of Table IX or Figure 6.

4. It is pointed out that in this calculation the accurate estimation of the strength of the wind can be extremely critical.

5. These results of course only apply to an area of the sea in which only slight horizontal temperature variations exist. For a vessel traveling at high speed or for one cruising in an area of marked horizontal change, prediction of the afternoon effect is much less certain.

6. Range prediction from meteorological observations is further complicated by the fact that sometimes the past history of the water mass is involved. For example, thermal stability near the surface may hold over from the preceding day. But it is the experience of our observers that through an understanding of the relative importance of the various factors and a little weather sense, one can often form a good opinion as to the vertical thermal structure near the surface without the necessity of computing the heat exchange.

Table I

										A	B	C	D	
										Cal/cm²/hr				
Time	Slide #	T°F Wet bulb	T°F Dry bulb	T°F Water	Vapor (mb) pressure differences	TW°F-TA°F	Wind Force	Cloud Amount	Barometric pressure (mb)	Heat lost evaporation	Heat lost conduction	Heat lost nocturnal radiation	Insolation	D-(A+B+C) Heat balance
07	351	54.3	62.3	67.4	11.14	5.1	1	0	1025	3.25	0.42	10.2	12.6	-1.25
08	352	54.8	62.7	67.2	10.67	4.5	1.5	0	1024	4.67	0.67	10.2	36.6	21.06
09	353	55.3	63.6	67.5	10.79	3.9	2	0	1024	6.30	0.79	10.2	57.6	40.31
10	354	54.6	63.8	67.6	11.57	3.8	2	0	1024	6.75	0.79	10.2	68.5	50.76
11	356	57.5	65.2	67.7	9.47	2.5	2	0	1024	5.55	0.50	9.6	79.2	63.55
12	359	56.9	65.8	68.3	10.76	2.5	3	0	1024	10.75	0.71	10.2	87.0	65.34
13	360	57.3	65.7	68.6	9.58	2.9	2	0	1024	5.58	0.83	10.2	86.4	69.79
14	362	58.6	66.8	68.7	9.82	1.9	2	0	1024	5.70	0.54	9.6	82.3	66.96
15	365	59.3	66.6	68.8	10.12	2.2	2	0	1023	5.91	0.63	10.8	66.0	48.66
16	367	59.8	66.4	68.8	8.54	2.4	2	0	1023	4.96	0.67	9.0	42.6	27.97
17	369	60.9	66.7	67.8	7.12	1.1	2	0	1023	4.17	0.33	8.4	28.2	15.30

Table II

	Total Solar radiation cal/cm²/7-17h	Heat loss: Nocturnal radiation cal/cm²/7-17h	Heat loss: Evaporation and conduction cal/cm²/7-17h	Residual heat cal/cm²/7-17h	Average Range	Wind force
Mar. 28/42	358	82	535	-259	2500	6
29	575	115	446	14	2500	5
30	204	23	138	43	2500	3
Apr. 15/42	277	30	26	221	2500	4
16	270	28	16	226	1950	3
17	282	30	25	227	2500	3
1	531	95	197	239	2500	3
Jan. 29/41	362	79	17	266	800	1-0
Apr. 24/42	476	52	146	278	2500	5-4
25	381	47	54	280	1200	4
14	413	44	48	321	2400	4
2	634	116	139	379	1950	3
13	543	87	74	382	1700	3
18	490	58	26	406	975	2
Feb. 21/41	532	92	29	411	950	1
Apr. 18/41	619	95	106	421	1500	3
4/42	623	100	87	436	2400	4
21	514	50	27	437	650	1-2
3	642	108	70	464	900	2
26	576	68	29	479	700	1-2
17/41	622	92	44	486	1150	2-3
22/42	729	92	83	557	900	2
19	715	80	25	610	700	2
20	725	82	21	622	500	1

Table III

a	b	c	d	e	f	g	h	i	j	k	l
Date and Time	Wet bulb T°F	Dry bulb T°F	Wet bulb-dry bulb	Relative humidity %	Water T°F	Water T°F-Air T°F	Saturation vapor pressure at water temp.	Vapor pressure at air T°F and humidity	Vapor pressure differences	Wind force	Cloud amount
Apr.											
08	58.9	66.7	7.8	62	67.4	0.7	22.9	13.8	9.1	2	3
09	60.7	66.5	5.8	72	67.6	1.1	23.1	16.0	7.1	2-3	0
10	61.1	66.9	5.8	72	68.1	1.2	23.5	16.3	7.2	4	1
11	62.4	66.4	4.0	80	68.0	1.6	23.4	17.8	5.6	4	1

m	n	o	p	q	r	s	t	u	v	w
Nocturnal radiation						Insolation				
At temp. and v.p. of air	Overcast correction	Corrected nocturnal radiation	Evaporation	Conduction	Total heat loss	Solar altitude°	Clear sky (Average precipitable water)	Cloud cover correction	Corrected insolation	Corrected insolation minus heat loss
9.4	0	9.4	5.3	.1	14.8	29	36	7.6	28	13
8.7	0	8.7	5.6	.3	15.6	45	58	0	58	43
8.6	0	8.6	12.6	.5	21.7	54	69	4.8	64	42
8.1	0	8.1	9.8	.7	18.6	61	75	5.3	70	51

All heat values expressed in calories per square centimeter per hour

Table IV

For obtaining the relative humidity of the air

Temperature of the air, dry-bulb thermometer	Difference between dry-bulb and wet-bulb readings									
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°
°F	%	%	%	%	%	%	%	%	%	%
40	92	84	76	68	59	52	44	37	30	22
42	92	84	77	69	61	54	47	40	33	26
44	92	85	78	70	63	56	49	43	36	29
46	93	85	79	72	65	58	51	45	38	32
48	93	86	79	73	66	60	53	47	41	35
50	93	87	80	74	67	61	55	49	43	37
52	94	87	81	75	69	63	57	51	46	40
54	94	88	82	76	70	64	59	53	48	42
56	94	88	82	77	71	65	60	55	50	44
58	94	89	83	78	72	67	61	56	51	46
60	94	89	84	78	73	68	63	58	53	48
62	95	89	84	79	74	69	64	59	54	50
64	95	90	85	79	74	70	65	60	56	51
66	95	90	85	80	75	71	66	61	57	53
68	95	90	85	81	76	71	67	63	58	54
70	95	90	86	81	77	72	68	64	60	55
72	95	91	86	82	77	73	69	65	61	57
74	95	91	86	82	78	74	70	66	62	58
76	95	91	87	82	78	74	70	66	63	59
78	96	91	87	83	79	75	71	67	63	60
80	96	92	87	83	79	75	72	68	64	61
82	96	92	88	84	80	76	72	69	65	62
84	96	92	88	84	80	77	73	69	66	63
86	96	92	88	84	81	77	73	70	67	63
88	96	92	88	85	81	77	74	71	67	64
90	96	92	88	85	81	78	74	71	68	65

Table V

PRESSURE OF AQUEOUS VAPOR OVER WATER IN MILLIBARS

Temp. °F	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
40	8.39	8.42	8.45	8.49	8.52	8.55	8.59	8.62	8.65	8.69
41	8.72	8.75	8.79	8.82	8.86	8.89	8.93	8.96	8.99	9.03
42	9.07	9.10	9.14	9.17	9.21	9.24	9.28	9.31	9.35	9.38
43	9.42	9.46	9.50	9.53	9.57	9.60	9.64	9.68	9.72	9.75
44	9.79	9.83	9.86	9.90	9.94	9.98	10.02	10.05	10.09	10.13
45	10.17	10.21	10.25	10.28	10.33	10.37	10.41	10.44	10.48	10.52
46	10.57	10.61	10.65	10.69	10.72	10.77	10.81	10.85	10.89	10.93
47	10.97	11.01	11.06	11.10	11.14	11.18	11.22	11.26	11.31	11.35
48	11.40	11.44	11.48	11.52	11.56	11.61	11.65	11.70	11.74	11.78
49	11.83	11.87	11.92	11.96	12.01	12.05	12.10	12.14	12.19	12.23
50	12.28	12.32	12.37	12.41	12.46	12.51	12.56	12.60	12.65	12.70
51	12.74	12.79	12.84	12.89	12.94	12.98	13.03	13.08	13.13	13.17
52	13.22	13.27	13.32	13.37	13.42	13.47	13.52	13.57	13.62	13.67
53	13.72	13.77	13.82	13.87	13.92	13.98	14.03	14.08	14.13	14.18
54	14.23	14.28	14.34	14.39	14.44	14.49	14.55	14.60	14.66	14.71
55	14.76	14.82	14.87	14.92	14.98	15.03	15.09	15.14	15.20	15.25
56	15.31	15.36	15.42	15.48	15.53	15.59	15.65	15.70	15.76	15.81
57	15.87	15.93	15.99	16.04	16.10	16.16	16.22	16.28	16.34	16.39
58	16.45	16.51	16.57	16.63	16.69	16.75	16.81	16.87	16.94	17.00
59	17.06	17.12	17.18	17.24	17.30	17.37	17.43	17.49	17.55	17.61
60	17.68	17.74	17.81	17.87	17.93	18.00	18.06	18.12	18.19	18.25
61	18.32	18.38	18.45	18.51	18.58	18.64	18.71	18.78	18.85	18.91
62	18.98	19.05	19.11	19.18	19.24	19.31	19.38	19.45	19.52	19.59
63	19.66	19.73	19.80	19.86	19.94	20.01	20.08	20.15	20.22	20.29
64	20.36	20.43	20.50	20.58	20.65	20.72	20.79	20.86	20.94	21.01
65	21.08	21.16	21.23	21.31	21.38	21.46	21.53	21.61	21.68	21.75
66	21.83	21.91	21.98	22.06	22.14	22.21	22.29	22.37	22.45	22.52
67	22.60	22.68	22.76	22.84	22.92	22.99	23.07	23.15	23.23	23.32
68	23.40	23.47	23.56	23.64	23.72	23.80	23.88	23.97	24.05	24.13
69	24.21	24.29	24.38	24.46	24.55	24.63	24.72	24.80	24.88	24.97
70	25.06	25.14	25.23	25.31	25.40	25.49	25.57	25.66	25.75	25.83
71	25.92	26.01	26.10	26.19	26.28	26.37	26.46	26.55	26.64	26.73
72	26.82	26.91	27.00	27.09	27.18	27.27	27.37	27.46	27.55	27.64
73	27.74	27.83	27.93	28.02	28.11	28.21	28.30	28.40	28.49	28.59
74	28.69	28.78	28.88	28.97	29.07	29.17	29.27	29.37	29.47	29.56
75	29.66	29.76	29.86	29.96	30.06	30.16	30.26	30.36	30.46	30.57
76	30.67	30.77	30.87	30.98	31.08	31.18	31.29	31.39	31.49	31.60
77	31.70	31.81	31.91	32.02	32.13	32.23	32.34	32.45	32.55	32.66
78	32.77	32.88	32.99	33.10	33.20	33.31	33.42	33.53	33.64	33.76
79	33.87	33.98	34.09	34.20	34.31	34.43	34.54	34.65	34.76	34.88
80	35.00	35.11	35.22	35.34	35.46	35.57	35.69	35.80	35.92	36.03
81	36.15	36.27	36.39	36.51	36.63	36.75	36.87	36.99	37.11	37.23
82	37.35	37.47	37.59	37.71	37.84	37.96	38.08	38.21	38.33	38.45
83	38.58	38.70	38.83	38.95	39.08	39.20	39.33	39.46	39.59	39.71
84	39.84	39.97	40.10	40.23	40.36	40.48	40.62	40.75	40.88	41.01
85	41.14	41.27	41.41	41.54	41.67	41.80	41.94	42.07	42.40	42.34
86	42.48	42.61	42.75	42.88	43.02	43.16	43.30	43.43	43.57	43.71
87	43.85	43.99	44.13	44.27	44.41	44.55	44.69	44.83	44.97	45.12
88	45.26	45.40	45.55	45.69	45.83	45.98	46.13	46.27	46.42	46.56
89	46.71	46.86	47.01	47.16	47.30	47.45	47.60	47.75	47.90	48.05
90	48.20	48.35	48.51	48.66	48.81	48.96	49.12	49.27	49.43	49.58

Computed from Smithsonian Meteorological Table No. 75
using 1 inch equivalent to 33.86395 millibars.

Table VI

PRESSURE OF AQUEOUS VAPOR

TEMP.	RELATIVE HUMIDITY, OR PERCENTAGE OF SATURATION										
	100	95	90	85	80	75	70	65	60	55	50
Dry °F	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.	mb.
50	12.3	11.7	11.0	10.4	9.8	9.2	8.6	8.0	7.4	6.8	6.1
52	13.2	12.6	11.9	11.2	10.6	9.9	9.2	8.6	7.9	7.3	6.6
54	14.2	13.5	12.8	12.1	11.4	10.7	10.0	9.2	8.5	7.8	7.1
56	15.3	14.5	13.8	13.0	12.2	11.5	10.7	10.0	9.2	8.4	7.7
58	16.4	15.6	14.8	14.0	13.2	12.3	11.5	10.7	9.9	9.0	8.2
60	17.7	16.4	15.9	15.0	14.1	13.3	12.4	11.5	10.6	9.7	8.8
62	19.0	18.0	17.1	16.1	15.2	14.2	13.3	12.3	11.4	10.4	9.5
64	20.4	19.3	18.3	17.3	16.3	15.3	14.2	13.2	12.2	11.2	10.2
66	21.8	20.7	19.6	18.6	17.5	16.4	15.3	14.2	13.1	12.0	10.9
68	23.4	22.2	21.1	19.9	18.7	17.6	16.4	15.2	14.0	12.9	11.7
70	25.1	23.8	22.6	21.3	20.0	18.8	17.5	16.3	15.0	13.8	12.5
72	26.8	25.5	24.1	22.8	21.5	20.1	18.8	17.4	16.1	14.8	13.4
74	28.7	27.3	25.8	24.4	23.0	21.5	20.1	18.6	17.2	15.8	14.3
76	30.7	29.1	27.6	26.1	24.5	23.0	21.5	19.9	18.4	16.9	15.3
78	32.8	31.1	29.5	27.8	26.2	24.6	22.9	21.3	19.7	18.0	16.4
80	35.0	33.2	31.5	29.8	28.0	26.2	24.5	22.8	21.0	19.2	17.5
82	37.4	35.5	33.6	31.8	29.9	28.0	26.1	24.3	22.4	20.5	18.7
84	39.8	37.8	35.9	33.9	31.9	29.9	27.9	25.9	23.9	21.9	19.9
86	42.5	40.4	38.2	36.1	34.0	31.9	29.7	27.6	25.5	23.4	21.2
88	45.3	43.0	40.7	38.5	36.2	34.0	31.7	29.4	27.2	24.9	22.6
90	48.2	45.8	43.4	41.0	38.6	36.2	33.7	31.3	28.9	26.5	24.1
92	51.3	48.7	46.2	43.6	41.0	38.5	35.9	33.4	30.8	28.2	25.7
94	54.6	51.9	49.1	46.4	43.7	40.9	38.2	35.5	32.8	30.0	27.3
96	58.0	55.2	52.2	49.3	46.4	43.5	40.6	37.7	34.8	31.9	29.0
98	61.7	58.6	55.5	52.4	49.4	46.3	43.2	40.1	37.0	33.9	30.8

Table VII

Heat loss by evaporation

Wind force, Beaufort	1	2	3	4	5	6
Cal/cm^2/hour	.29	.58	1.0	1.75	3.0	4.67

The factor under the various wind forces, when multiplied by the vapor pressure difference, gives the heat loss by evaporation in calories per square cm. per hour.

Table VIII

Heat loss by conduction

Wind force, Beaufort	1	2	3	4	5	6
Cal/cm^2/hour	.08	.21	.29	.42	.54	.67

The factor under the wind forces, when multiplied by the difference between air and water temperatures, gives the heat loss by conduction in calories per square centimeter per hour.

Table IX

ASSURED RANGE IN YARDS IN A LAYER OF DECREASING TEMPERATURE

Temperature Difference between the surface and 30 feet	Surface Temperature 40°	50°	60°	70°	80°
.1°	1800	2000	2200	2400	2600
.2°	1300	1400	1500	1700	1800
.3°	1100	1200	1200	1400	1500
.4°	900	1000	1100	1200	1300
.5°	800	900	950	1100	1200
.6°	750	800	850	950	1000
.7°	700	750	800	900	950
.8°	650	700	750	850	900
.9°	600	650	700	800	850
1.0°	550	600	650	750	800
1.2°	550	550	600	700	750
1.5°	475	500	550	600	650
2.0°	400	425	450	500	550
3.0°	350	375	400	425	450
4.0°	300	325	350	375	400
5.0°	250	275	300	325	350
8.0°	200	225	225	250	275

The ranges listed here are for a projector depth of 8 feet, and are therefore conservative values for greater depths of projection.

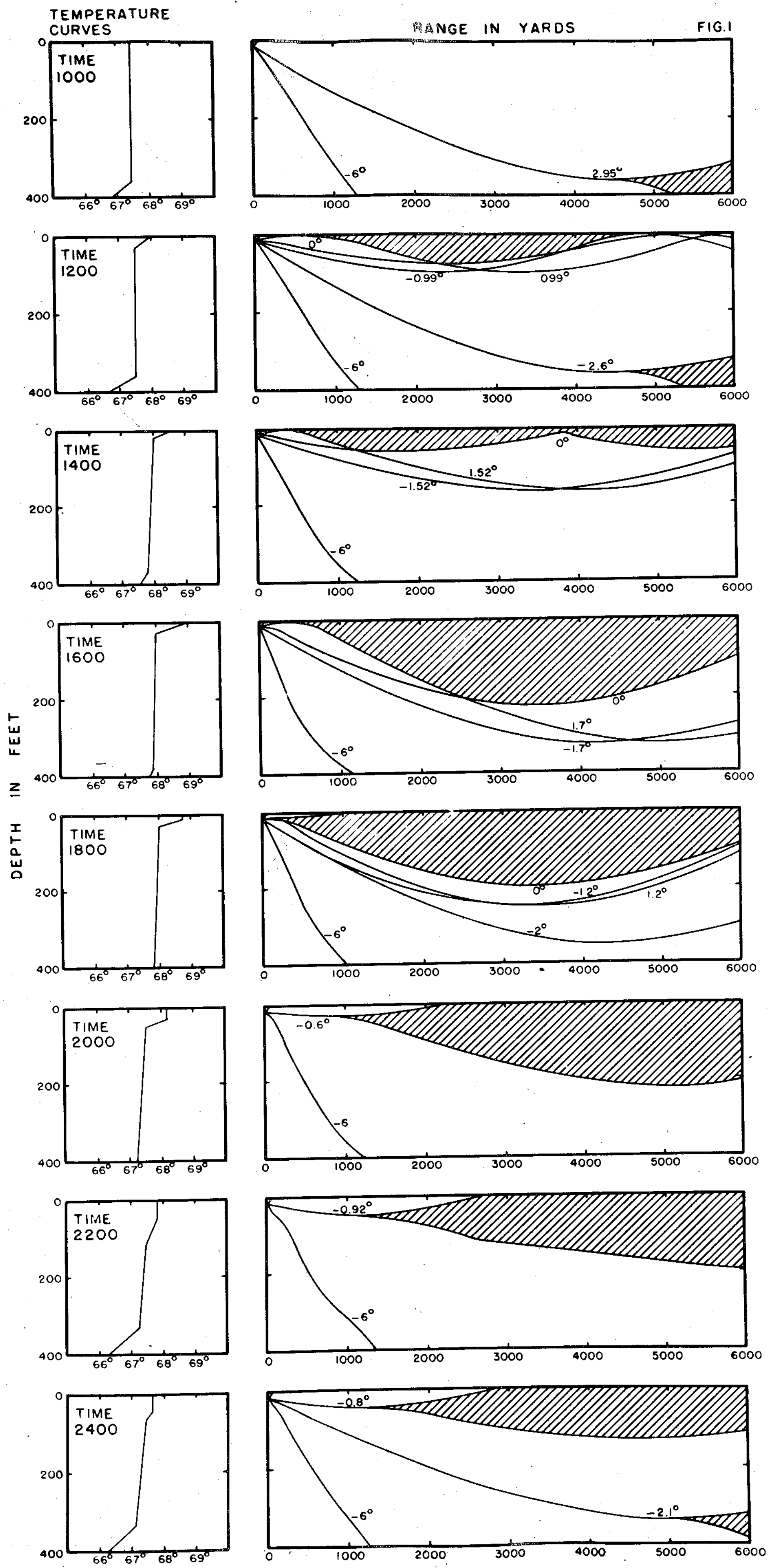

TEMPERATURE CURVES
RANGE IN YARDS
DEPTH IN FEET
TIME 1000
TIME 1200
TIME 1400
TIME 1600
TIME 1800
TIME 2000
TIME 2200
TIME 2400
0
200
400
66° 67° 68° 69°
0 1000 2000 3000 4000 5000 6000
-6°
2.95°
0°
-0.99°
0.99°
-2.6°
1.52°
-1.52°
1.7°
-1.7°
-1.2°
1.2°
-2°
-0.6°
-6
-0.92°
-0.8°
-2.1°

FIG. 1

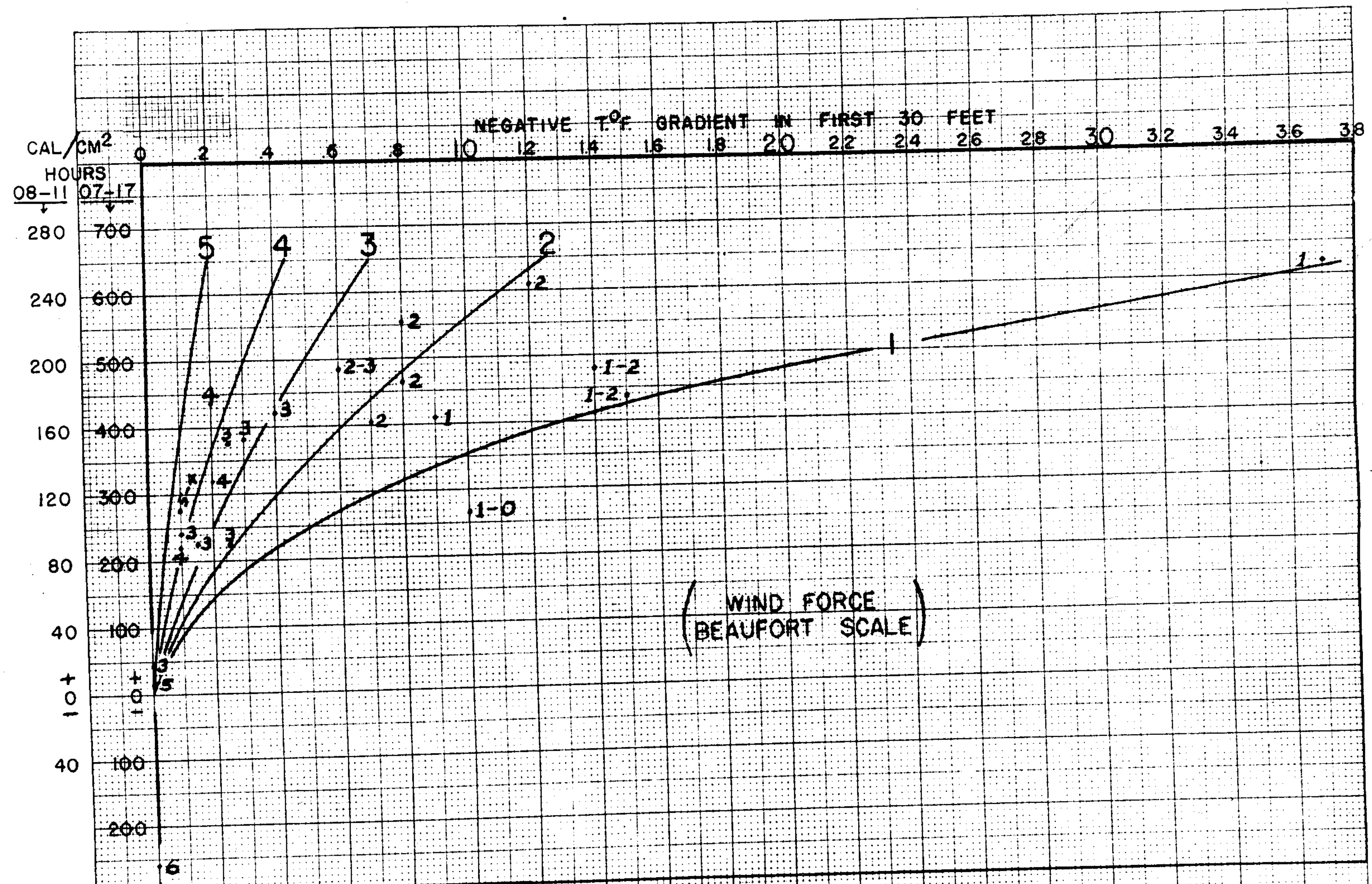

NEGATIVE T°F. GRADIENT IN FIRST 30 FEET
CAL/CM²
HOURS
08–11
07–17
(WIND FORCE
BEAUFORT SCALE)

Fig. 2

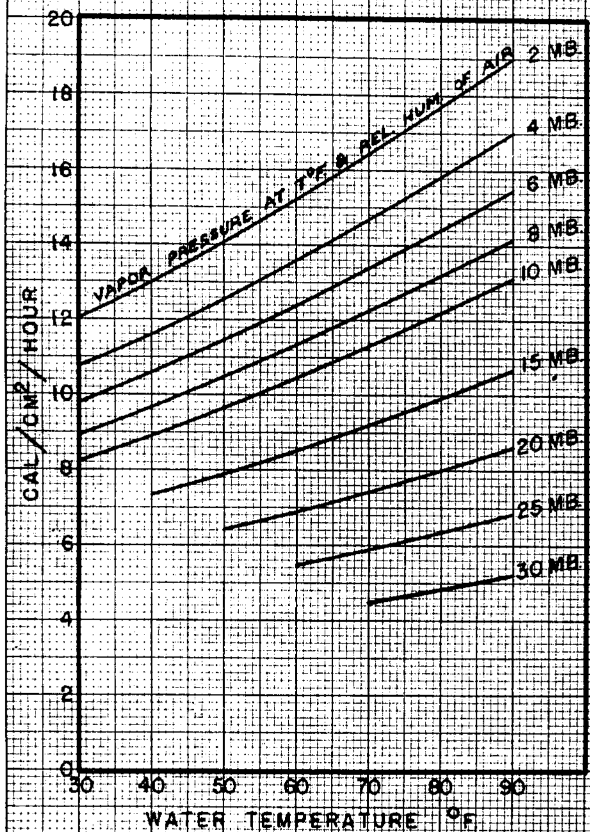


FIG 3 NOCTURNAL RADIATION

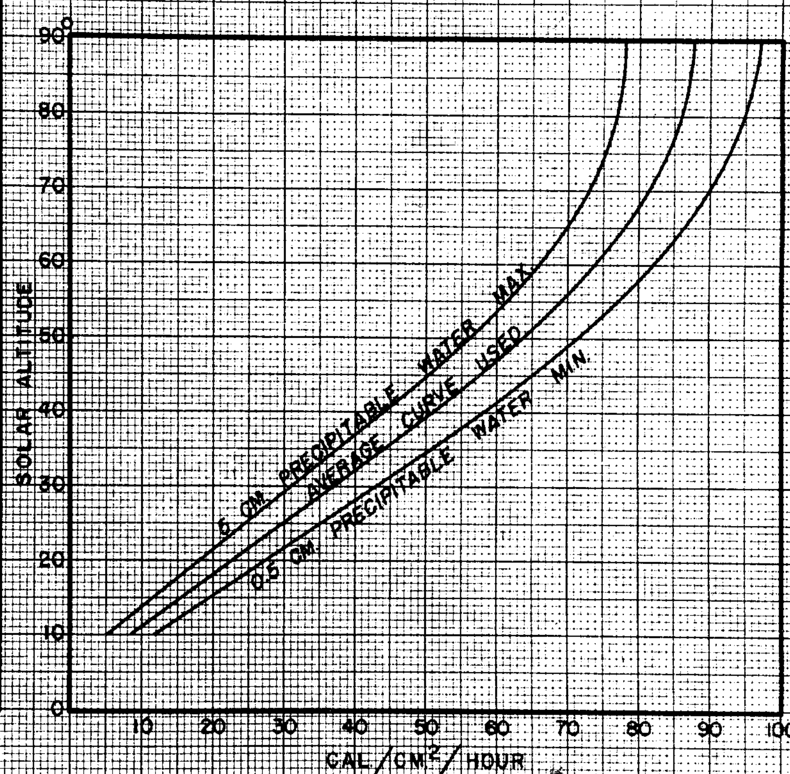


FIG 4 CLEAR SKY INSOLATION VALUES

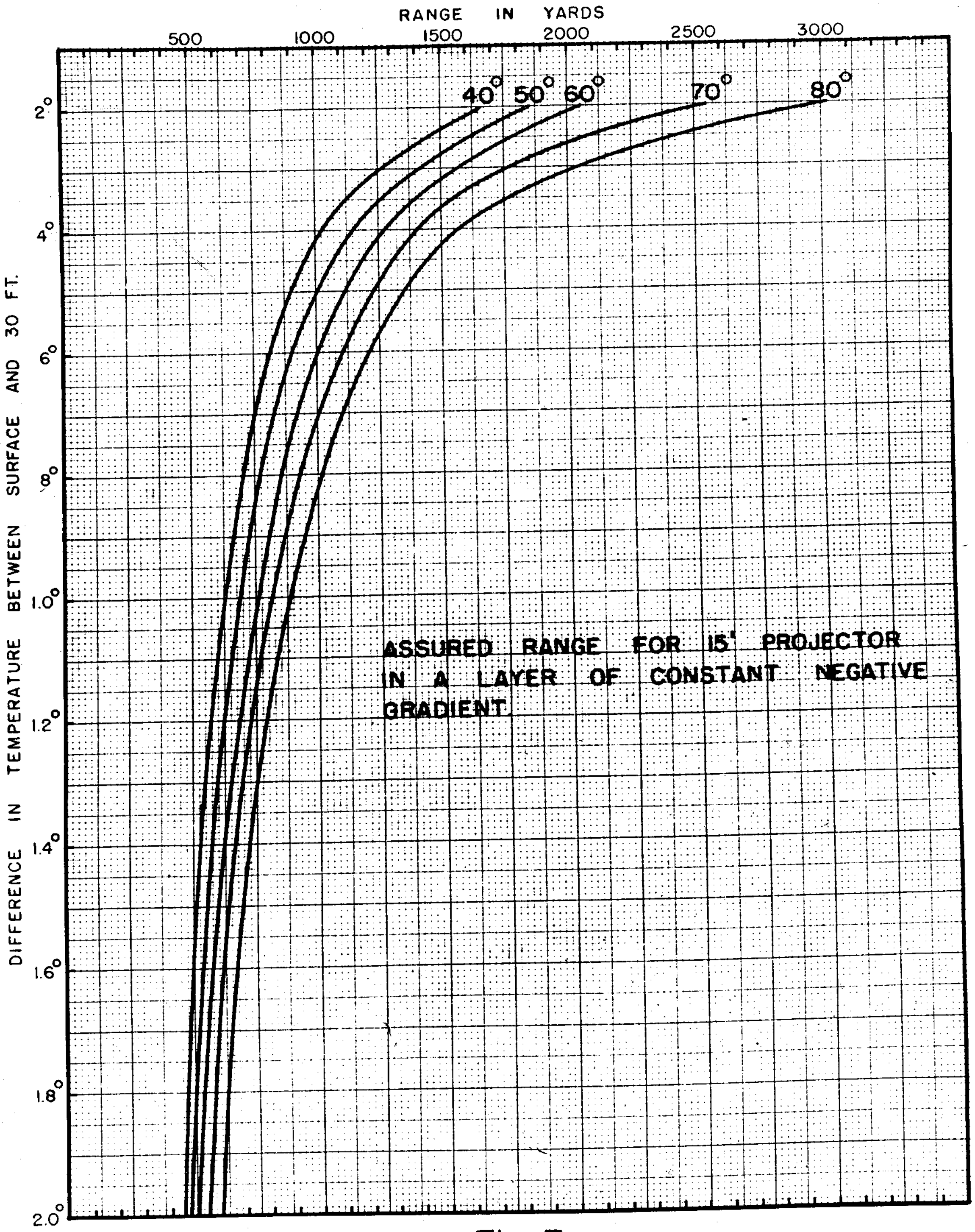

RANGE IN YARDS
500
1000
1500
2000
2500
3000
40°
50°
60°
70°
80°
DIFFERENCE IN TEMPERATURE BETWEEN SURFACE AND 30 FT.
2°
4°
6°
8°
1.0°
1.2°
1.4°
1.6°
1.8°
2.0°
ASSURED RANGE FOR 15' PROJECTOR
IN A LAYER OF CONSTANT NEGATIVE
GRADIENT

Fig. 5

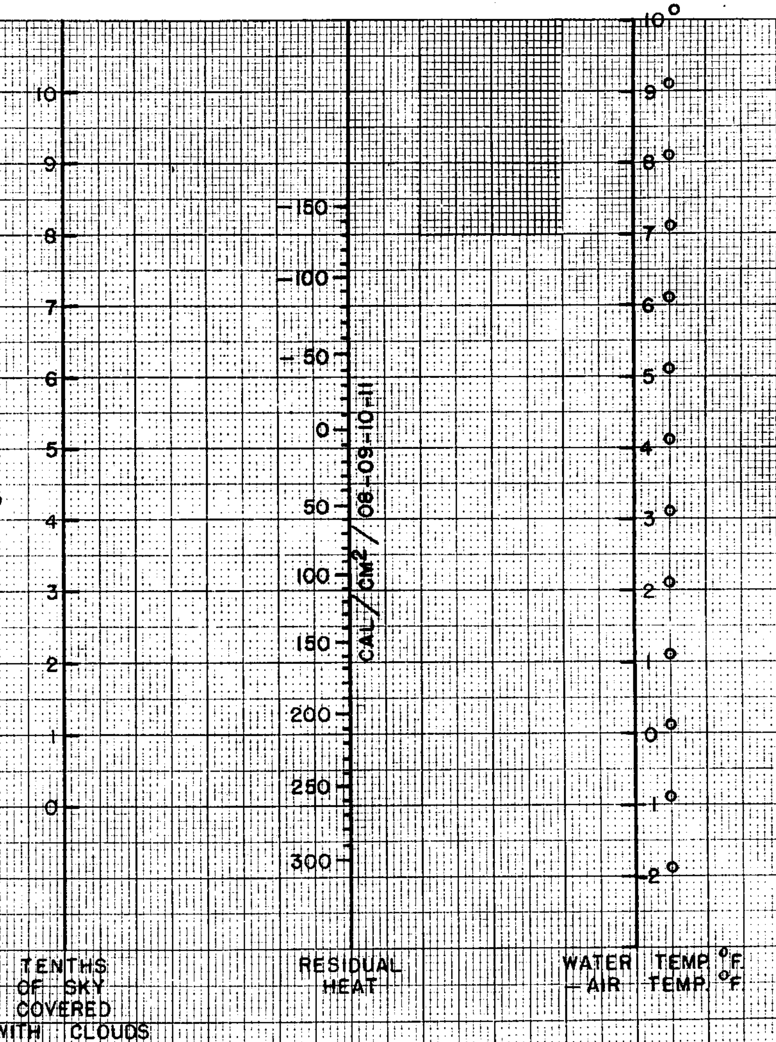
FIG. 6

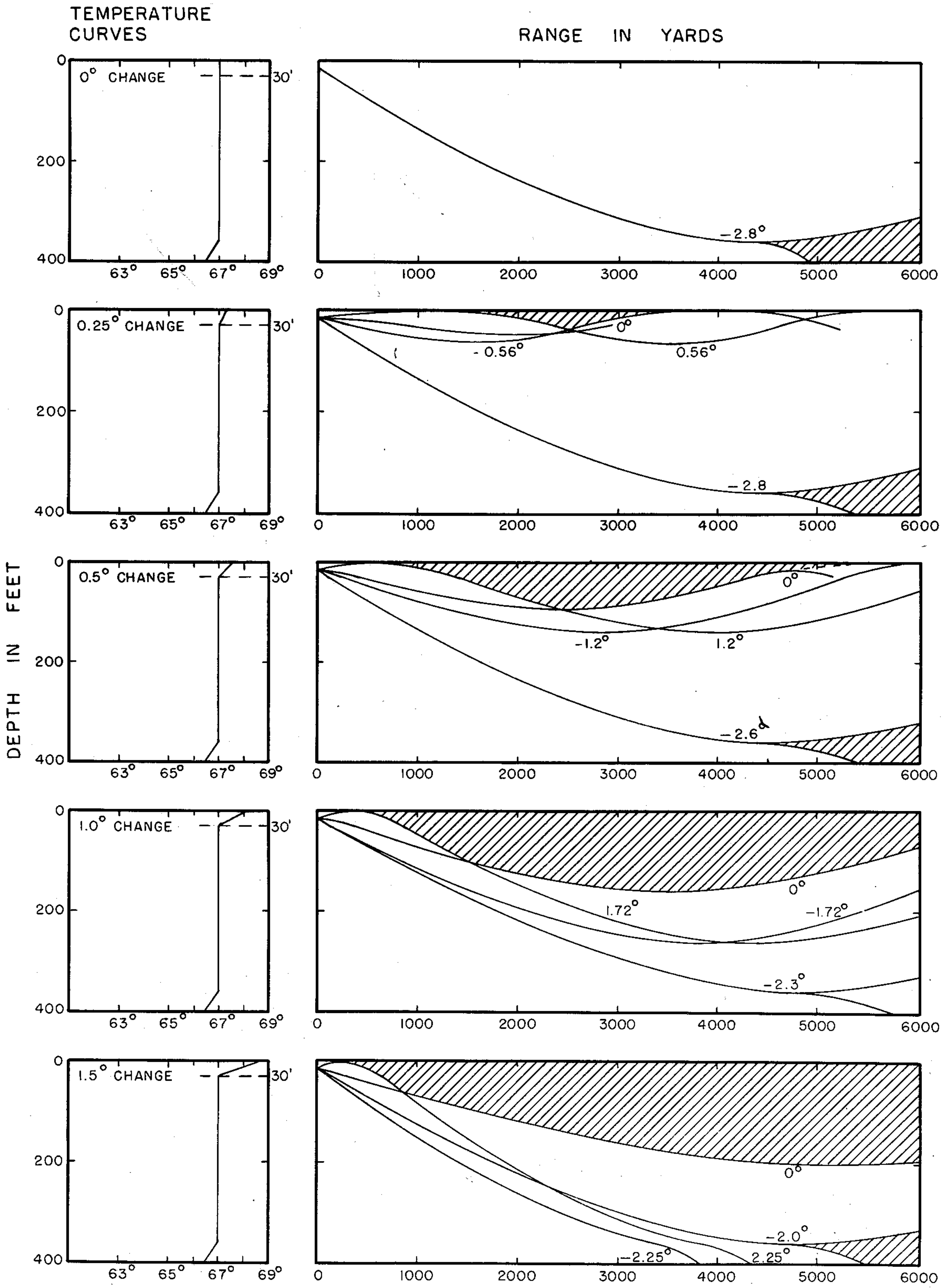
ESTIMATION OF RESIDUAL HEAT FROM AVERAGE CLOUD COVER AND AVERAGE DIFFERENCE BETWEEN WATER AND AIR TEMP.

0800–1100

WITH NOON SOLAR ALTITUDE BETWEEN 50°–80°

THE AVERAGE DIFFERENCE BETWEEN HEAT DETERMINED BY NOMOGRAM AND BY THE OTHER METHOD IS ± 32





TEMPERATURE CURVES
RANGE IN YARDS
DEPTH IN FEET
0° CHANGE
0.25° CHANGE
0.5° CHANGE
1.0° CHANGE
1.5° CHANGE
30'
0
200
400
63°
65°
67°
69°
1000
2000
3000
4000
5000
6000
-2.8°
-0.56°
0.56°
0°
-2.8
-1.2°
1.2°
-2.6°
1.72°
-1.72°
-2.3°
-2.0°
-2.25°
2.25°

FIG. 7.

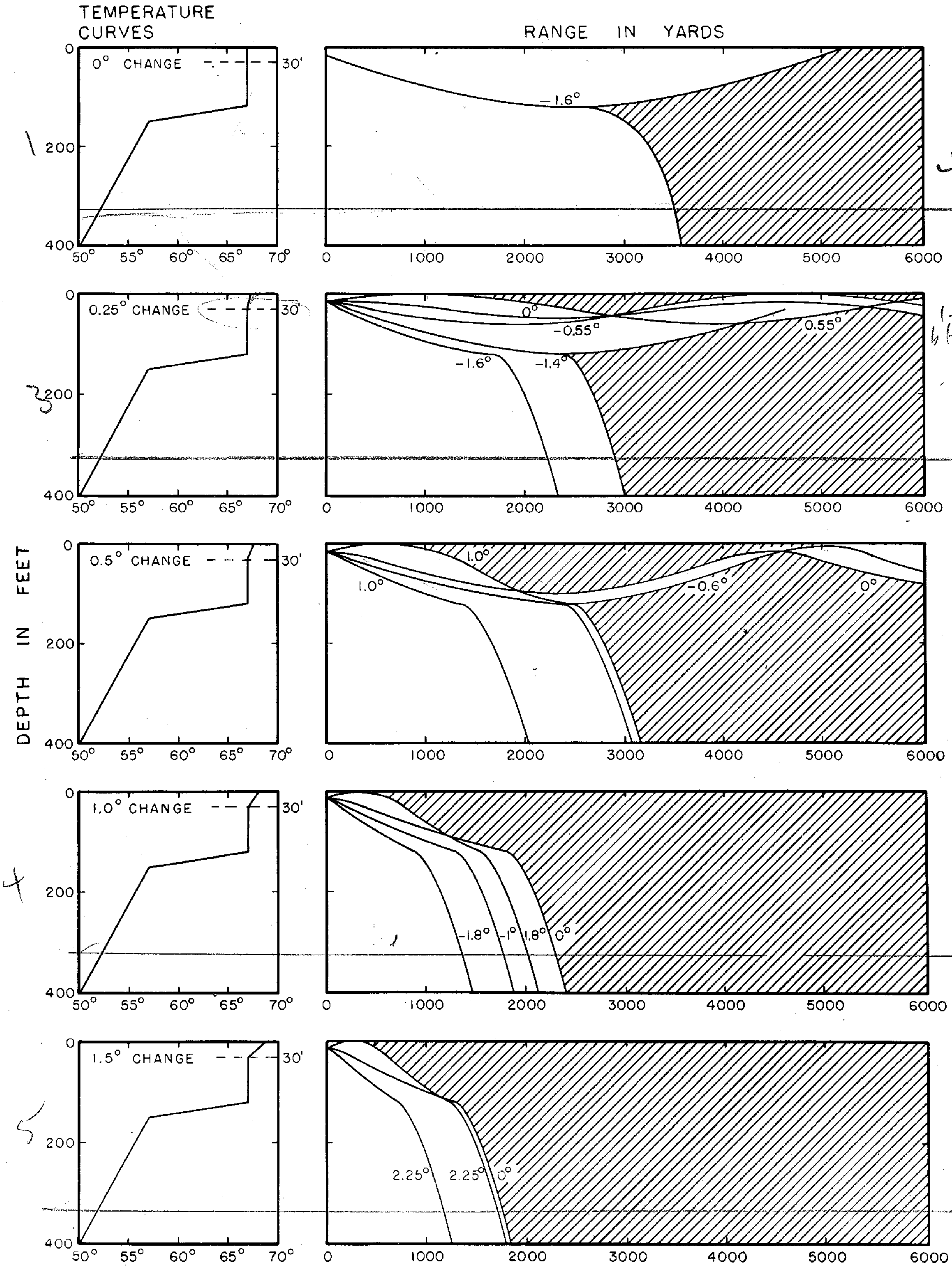

TEMPERATURE CURVES
RANGE IN YARDS
DEPTH IN FEET
0° CHANGE
30'
−1.6°
0.25° CHANGE
0°
−0.55°
0.55°
−1.6°
−1.4°
0.5° CHANGE
1.0°
1.0°
−0.6°
0°
1.0° CHANGE
−1.8°
−1°
1.8°
0°
1.5° CHANGE
2.25°
2.25°
0°
0
200
400
50°
55°
60°
65°
70°
0
1000
2000
3000
4000
5000
6000

FIG. 8

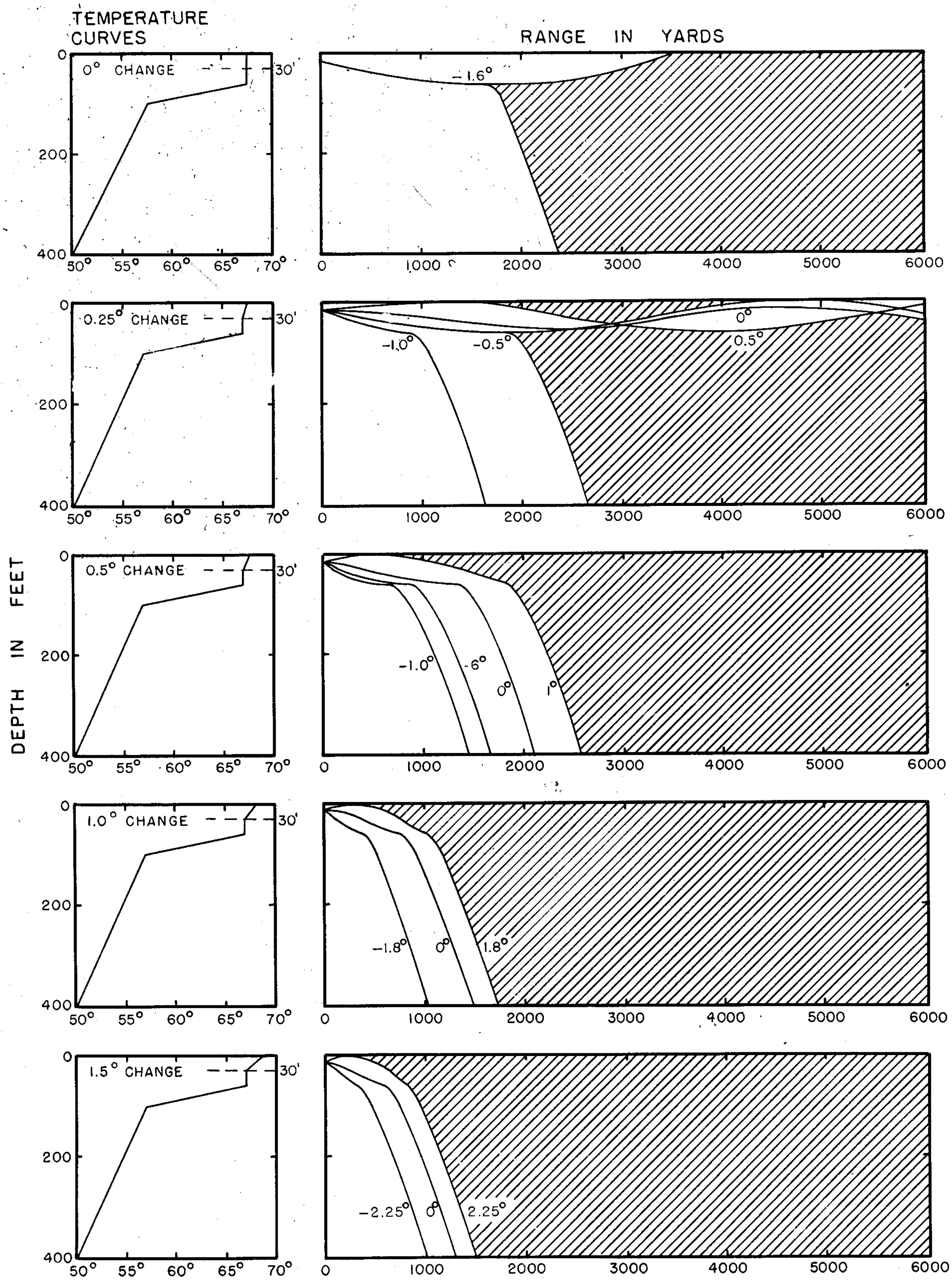

TEMPERATURE CURVES
RANGE IN YARDS
DEPTH IN FEET
0° CHANGE
0.25° CHANGE
0.5° CHANGE
1.0° CHANGE
1.5° CHANGE
30'
-1.6°
-1.0°
-0.5°
0°
0.5°
-6°
1°
-1.8°
1.8°
-2.25°
2.25°
0
200
400
50°
55°
60°
65°
70°
1000
2000
3000
4000
5000
6000

FIG. 9