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TECHNICAL REPORT

ASWEPS REPORT NO. 9

DIURNAL TEMPERATURE CHANGES AT OCEAN STATION ECHO–SEPTEMBER 1959

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ABSTRACT

Analysis of nearly 900 bathythermograms taken at half-hourly intervals at Ocean Weather Station ECHO between 2 and 21 September 1959 reveals that convective mixing, the most easily identified physical process involved in the daily heating and cooling cycle, extended to a depth of 60 feet near sunrise. Measurement of radiational heating was complicated by apparent internal wave action on a weak thermocline at 60 feet. Estimation of the coefficient of thermal conductivity from the data yielded a value much lower than expected because of simultaneous turbulent heat transfer. After elimination of known sources of temperature variations (instrumental or human errors), advective heat exchange was revealed to be the major source of remaining variations. The energy involved in advection was much greater than that involved in the vertical processes of heating, cooling, and convective mixing.

FOREWORD

Short-term prediction of environmental factors is an essential part of the AntiSubmarine Warfare Environmental Prediction System (ASWEPS). The physical processes affecting oceanic environments must be understood before prediction techniques can be formulated. Recognizing that observations of diurnal variations in the open ocean are scarce, the Oceanographic Office has conducted a series of observation programs covering a limited area in cooperation with the U. S. Coast Guard.

This report describes one aspect of the observational results: an analysis of the diurnal processes in the mid-Atlantic during summer. Therefore it serves as a forerunner to a complete understanding of the processes which, in general, govern short-term environmental changes.

E. C. STEPHAN
Rear Admiral, U. S. Navy
Commander

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INTRODUCTION

The ASWEPS research program being conducted at the Hydrographic Office* includes a systematic investigation of the physical processes involved in the daily heating cycle of the upper layers of the ocean. This investigation is being conducted in order to determine the effect of these processes on the thermal structure and to devise an analytical short-range prediction technique. The approach follows the method outlined by Schule (1952). A thermal structure prediction program based on meteorological parameters has been tested by this office (Nix 1962). This report summarizes the results of an attempt to find the numerical values of some vertical physical processes in the water under conditions of minimal horizontal variations.

Many studies of diurnal temperature variations in lakes have been made (for example, Geiger, 1950); fewer studies of diurnal changes in the oceans have been made (for example, Sverdrup et al., 1942 and Defant, 1961). Perhaps the most extensive account is given by La Fond (1954) who considered inshore as well as deep-sea locations. Most of the oceanic studies were made at anchor stations of short duration. Because they are limited to shallow water, a comparatively large number of studies have been excluded from this discussion.

This report analyzes the results of an intensive survey conducted by personnel of the Hydrographic Office in September 1959 at Ocean Weather Station ECHO (35N, 48W). Half-hourly deep bathythermograph (BT) casts and several short series of shallow casts at 10-minute intervals were made. In addition, 93 Nansen casts were made in connection with a study of the seasonal halocline. BT data were carefully controlled for accuracy by reading slides immediately upon completion of an observation; instruments were replaced when gross errors appeared in the data. Thirteen instruments were used to obtain nearly 900 BT's between 2 and 21 September 1959. The mean diurnal temperature changes for a mid-latitude mid-oceanic location in late summer can be obtained from these observations.

METHOD OF ANALYSIS

All BT records were averaged for each hour of the day. Thus, the average for each hour represents between 27 and 49 observations taken during the period of the survey. The purpose of averaging is twofold; namely, (1) to provide hourly values of meteorological and astronomical variables for the computer prediction program, and (2) to remove or minimize horizontal factors, mainly advection and the horizontal component of diffusion, which are not used in the computer program. In addition, some of the vertical processes average out in desirable fashion; that is, the average thermal structure represents averages of cloudiness, wind (evaporation), sea condition (and therefore average turbulent mixing), and local cooling due to shower activity. Since the observations were taken over a period of 20 days, during which times of flood and ebb tides moved forward about 17 hours, tidal effect has almost been removed from the data.

* Redesignated U. S. Naval Oceanographic Office 10 July 1962

SURFACE CHARACTERISTICS

In order to determine whether seasonal influences were important, the data were divided into two time periods, covering approximately 10 days each. Mean hourly sea surface temperatures are plotted in Figure 1, which provides a graphic comparison of the mean temperature variations of the periods 2 to 10 September and 11 to 21 September. The curves are similar in shape and have almost identical mean values. Although slightly more heating occurs in the afternoon hours during the earlier period, data for the two periods were combined with the subsurface temperatures for the same period. The curves are nearly identical in value at night. The mean daily range in sea surface temperature was about 1.1° F.

SUBSURFACE TEMPERATURES

Subsurface temperatures were listed according to the standard SERC deck coding procedure used by this Office. This procedure records temperatures at 20-foot intervals between the surface and 360 feet and at 40-foot intervals between 360 and 880 feet. The influence of the daily temperature cycle was not expected to extend below a depth of 100 feet; therefore the mean hourly temperatures were computed only for the surface and for every 20-foot level to this depth. Table 1 lists the hourly means and standard deviations. The means have been plotted in Figure 2, which also shows times of local sunrise, noon, and sunset.

The temperature apparently fluctuates rather regularly and considerably at all levels; separation of the heating and cooling effects from those due to other influences such as internal waves becomes a problem. This problem was solved by analyzing the thermal structure in layers. Major daily thermal variations result from incoming solar radiation during daylight hours and from loss of heat during night hours. The latter of these effects may result in convection if density instability is produced.

As an aid to analysis, the temperature differences in five layers have been plotted (Figure 3). The resulting curves indicate that convection (zero gradient) began at 20 feet at 0200Z, 40 feet at 0500Z, 60 feet at 1000Z, and that it did not extend to 80 feet.

Figure 4, a further exposition of the layer analysis, shows the mean hourly temperature differences between the surface and 60 feet as compared to those in the layer between 60 and 100 feet. Diurnal changes are immediately apparent from the regularity of the curve for the upper layer and lack of regularity of the curve for the lower layer. Therefore, it can be concluded that diurnal effects were confined to depths between the surface and 60 feet at OWS ECHO in September 1959.

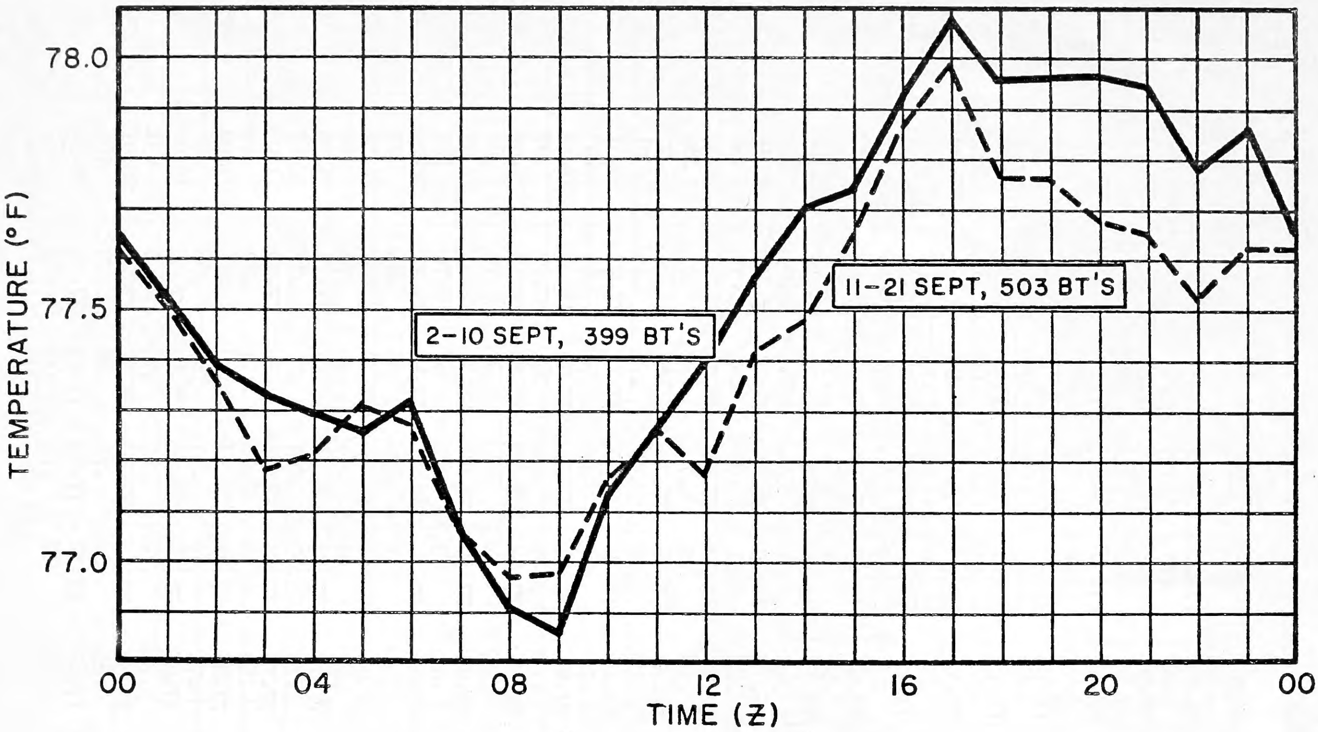


FIGURE I DIURNAL VARIATION OF SEA SURFACE TEMPERATURE, OWS ECHO, SEPTEMBER 1959

TABLE 1

Mean Hourly Temperatures and Standard Deviations ($^{\circ}$ F)

Hour (Z)	Surface	20 ft	40 ft	60 ft	80 ft	100 ft	No. of obs.
0000	77.62	77.60	77.51	77.41	77.33	77.19	41
	.63	.73	.75	.82	.86	.94	
0100	77.51	77.45	77.40	77.32	77.24	77.17	49
	.61	.61	.65	.72	.80	.85	
0200	77.36	77.36	77.31	77.25	77.19	77.02	48
	.61	.62	.65	.67	.72	.76	
0300	77.18	77.18	77.14	77.07	77.01	76.85	40
	.63	.65	.67	.70	.74	.77	
0400	77.21	77.22	77.19	77.15	77.08	76.98	37
	.63	.63	.63	.65	.69	.72	
0500	77.31	77.31	77.31	77.28	77.23	77.09	38
	.69	.69	.68	.71	.73	.85	
0600	77.27	77.29	77.28	77.22	77.12	76.93	36
	.66	.65	.67	.67	.76	.91	
0700	77.06	77.07	77.07	77.03	76.95	76.87	32
	.50	.51	.51	.52	.56	.61	
0800	76.97	76.99	77.01	76.92	76.86	76.73	32
	.62	.61	.62	.65	.65	.67	
0900	76.97	76.99	76.97	76.93	76.88	76.76	36
	.62	.61	.60	.59	.57	.66	
1000	77.16	77.19	77.21	77.17	77.06	76.89	35
	.70	.72	.72	.73	.80	.89	
1100	77.27	77.28	77.29	77.28	77.14	76.97	37
	.73	.72	.73	.75	.85	1.01	
1200	77.17	77.17	77.15	77.11	77.02	76.87	36
	.72	.73	.75	.78	.85	.95	
1300	77.41	77.35	77.33	77.26	77.18	77.10	49
	.73	.76	.77	.81	.89	.97	
1400	77.48	77.44	77.37	77.28	77.18	77.06	49
	.62	.64	.64	.69	.75	.84	
1500	77.64	77.59	77.46	77.34	77.23	77.07	48
	.62	.63	.62	.67	.76	.87	
1600	77.86	77.74	77.58	77.49	77.37	77.29	30
	.56	.51	.50	.56	.65	.75	
1700	77.99	77.88	77.75	77.59	77.44	77.32	27
	.62	.58	.59	.64	.78	.84	
1800	77.76	77.58	77.38	77.27	77.14	76.96	31
	.74	.69	.70	.72	.77	.84	
1900	77.76	77.63	77.42	77.30	77.20	77.05	32
	.63	.59	.66	.71	.79	.89	
2000	77.67	77.54	77.38	77.18	77.07	77.00	35
	.71	.69	.70	.81	.84	.86	
2100	77.65	77.54	77.36	77.17	77.06	76.93	34
	.78	.74	.71	.79	.85	.91	
2200	77.52	77.45	77.30	77.15	77.04	76.91	32
	.80	.80	.75	.76	.79	.86	
2300	77.62	77.52	77.40	77.25	77.09	76.92	32
	.83	.77	.75	.76	.73	.78	
						Total	896

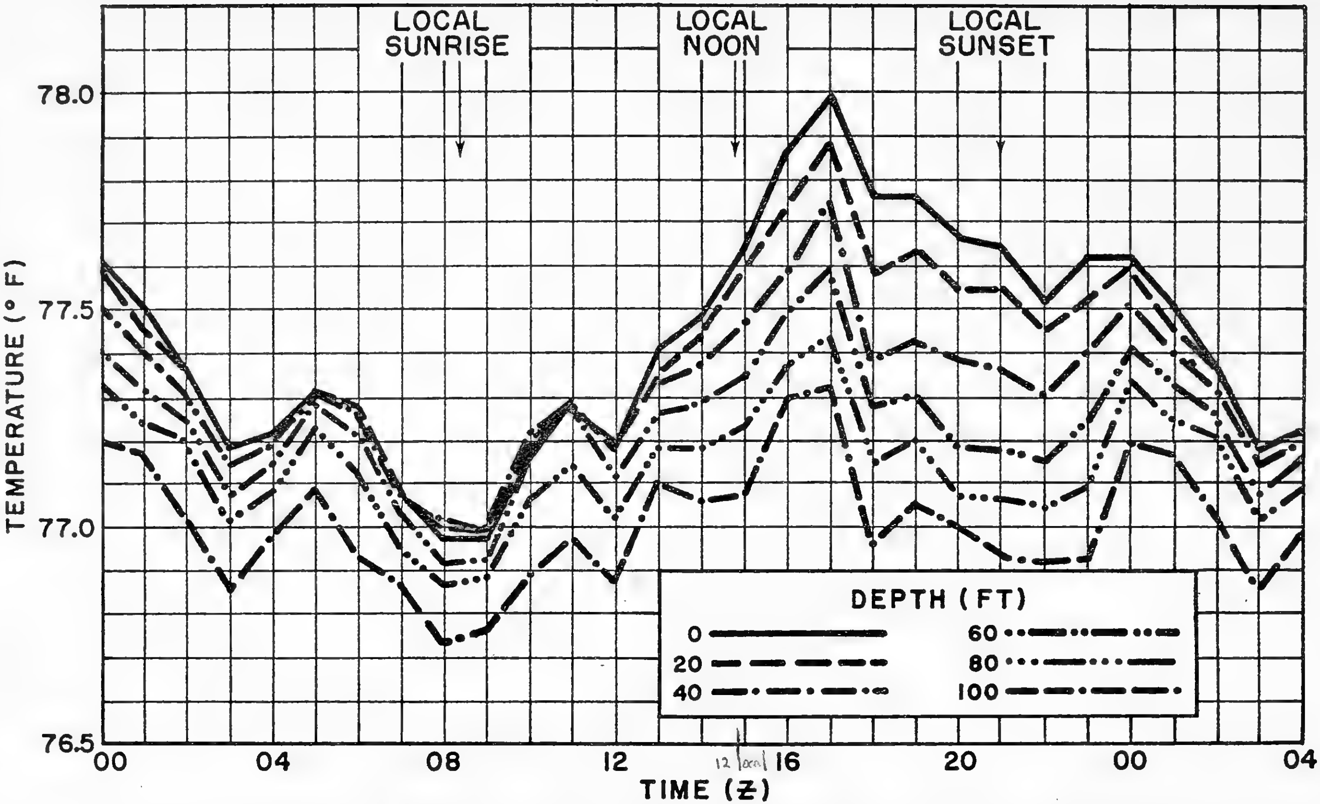


FIGURE 2 MEAN HOURLY TEMPERATURES, 2—21 SEPTEMBER

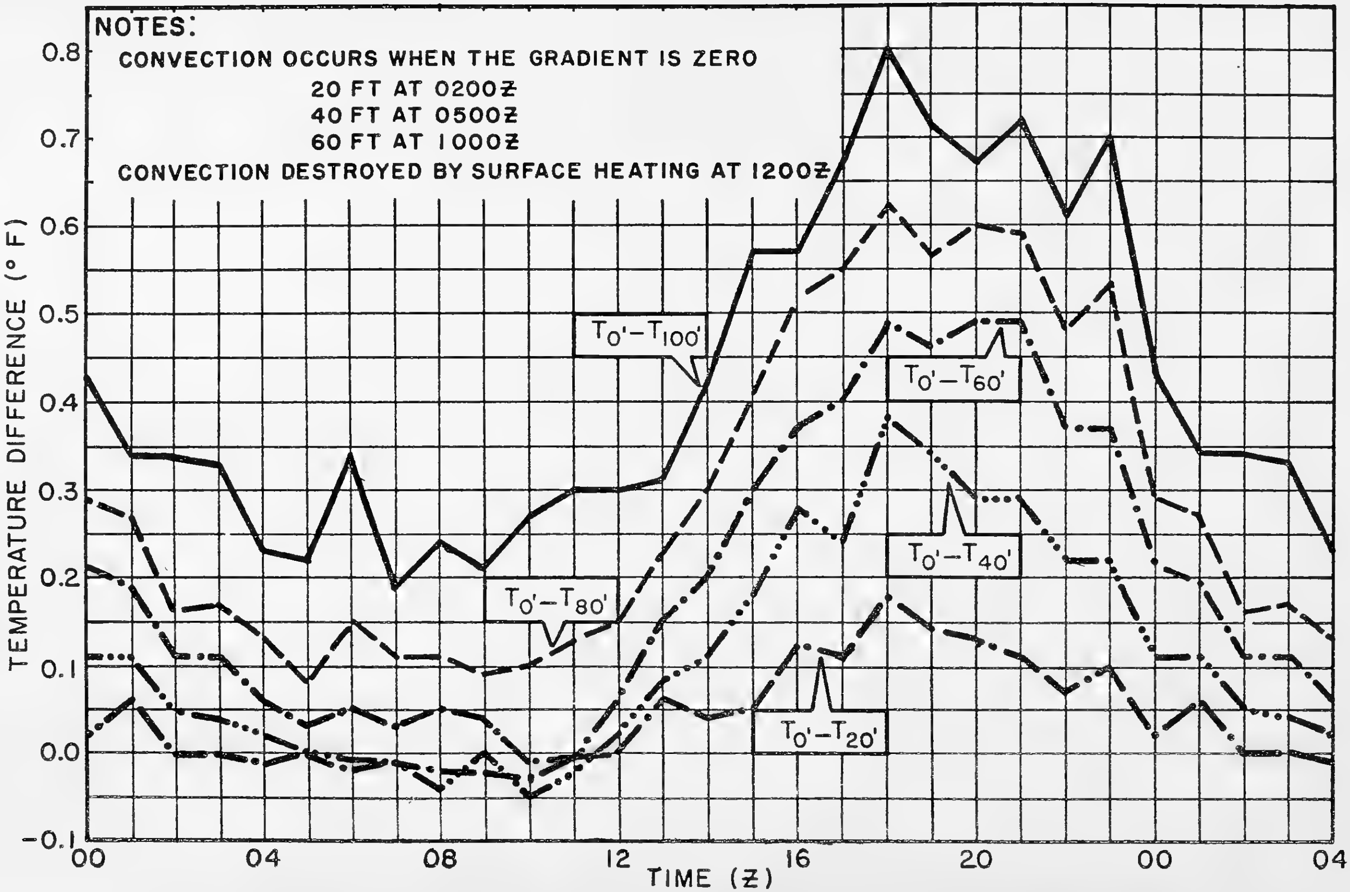


FIGURE 3 MEAN HOURLY TEMPERATURE DIFFERENCES BETWEEN SURFACE AND SUBSURFACE LEVELS

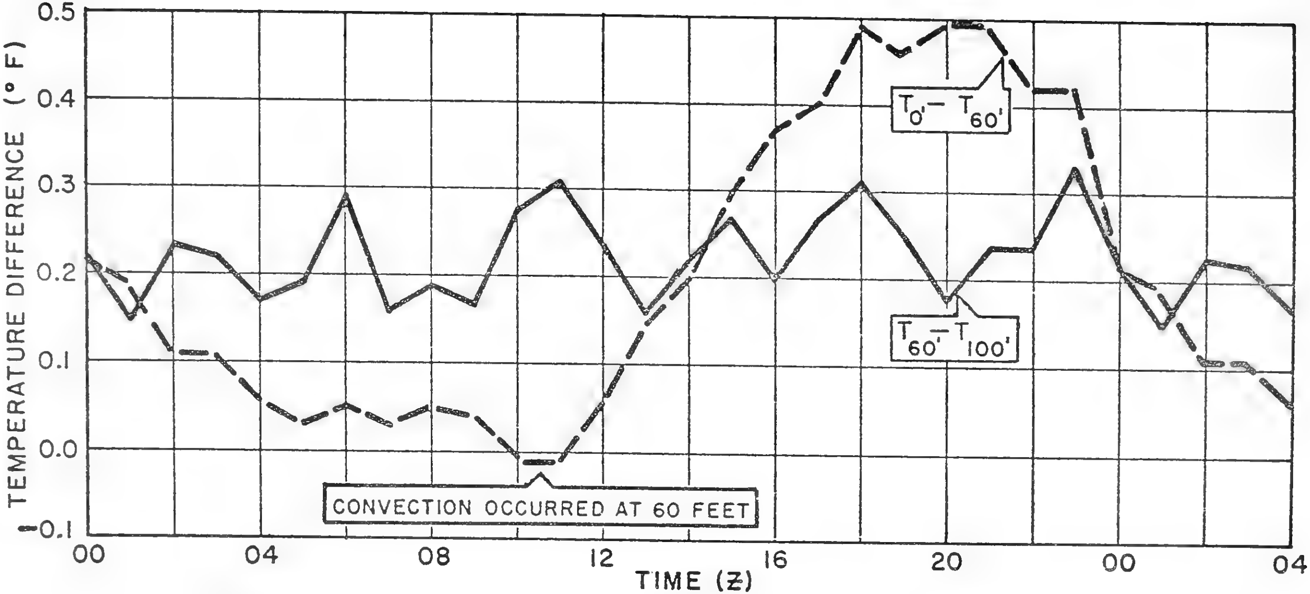


FIGURE 4 HOURLY TEMPERATURE DIFFERENCES IN TWO LAYERS

The above conclusion helps to explain hourly temperature fluctuations at 60 feet. The two regular wave cycles between sunset and sunrise in Figure 5 are apparently caused by internal waves. Two fluctuations during the daylight hours are partly masked by diurnal heating. If the curve for the 60- to 100-foot layer in Figure 4 is correct, heat changes at 60 feet were directly reflected at 100 feet. The maximum temperature at 1700Z at 60 feet (Figure 5) was about 0.2° F higher than the secondary maximum at 0000Z. This difference may be interpreted as the mean diurnal temperature range at 60 feet. Rough correction for this value in Figure 5 fails to eliminate the two fluctuations during the daylight hours. Thus, four internal waves are apparently revealed by the hourly analysis. The analysis automatically eliminates waves with frequencies of less than 2 hours. Since tidal effects have been largely eliminated by averaging the data over a period of 20 days, these internal waves must be stationary and are probably caused by some other phenomena. One theory of a possible cause is isostasy; that is, the waves may be caused by convection during which the water particles seek equilibrium after vertical transfer from the surface. Inasmuch as the convective process required 3 hours to progress from 20 to 40 feet and 5 hours to progress from 40 to 60 feet, this theory appears to be an unsatisfactory explanation of the internal waves.

Figures 6, 7, and 8 show the results of the convective process. Figure 6 illustrates depth of convection and time of maximum heating. Figure 7 shows mean BT's for each hour during the night; Figure 8 shows the same for daylight hours.

SENSIBLE HEAT CHANGES

Temperature fluctuations in the upper 60 feet are analogous to, but not identical to, changes in sensible heat content, which depend on the density changes. Salinity observations were obtained from the 93 Nansen casts. Possible diurnal changes in salinity could not be determined because these observations were not evenly distributed throughout the day. The majority were taken at 6-hourly intervals (0300Z, 0900Z, 1500Z, and 2100Z). Mean salinity values in Figure 9 show little diurnal vertical variation in the upper 20 meters; whereas the diurnal range of salinity was considerable at 40 meters. This range is probably due to fluctuations of the seasonal halocline. A mean salinity value of 36.25 ‰ was used with standard formulas for converting temperature into sensible heat.

Figure 10 shows hourly changes of total sensible heat content (Q) in the three 20-foot layers of the ocean. The curves closely resemble those of Figure 2, owing to use of the constant salinity value in the formulas. In order to outline the difference in heat content between layers more clearly, the differences between the first and second layers and between the second and third layers have been plotted in Figure 11. The relationship between heat content changes caused by solar heating and convection is also shown. The fact that increases in heat content due to solar radiation were practically simultaneous in all layers should be noted in this Figure. This simultaneity is due to high transparency of the water. Cooling due to heat loss at the surface progressed from

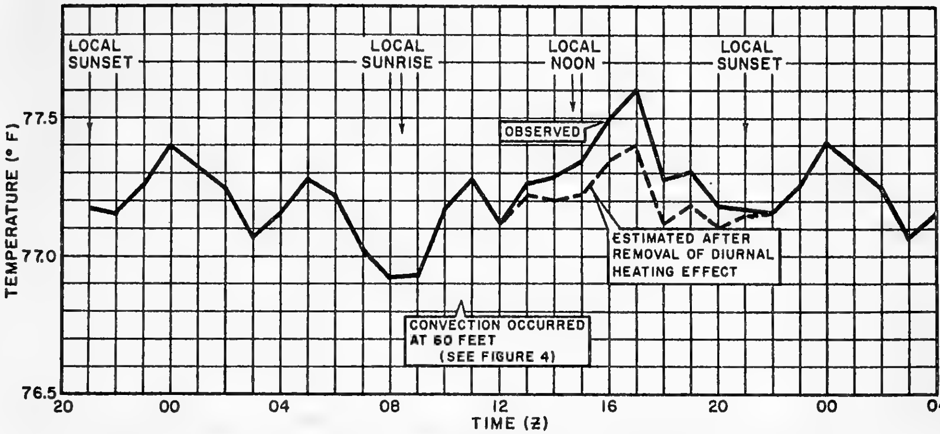


FIGURE 5 MEAN DIURNAL TEMPERATURE FLUCTUATIONS AT 60 FEET

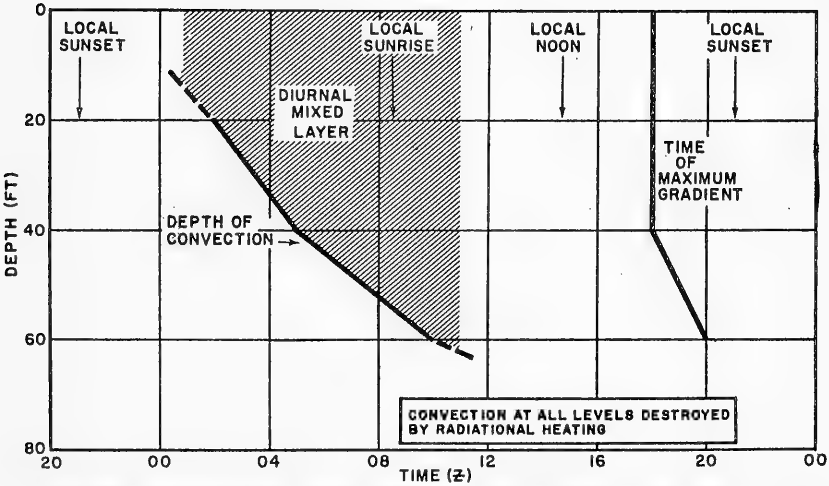


FIGURE 6 PHYSICAL PROCESSES OF THE DIURNAL HEATING CYCLE

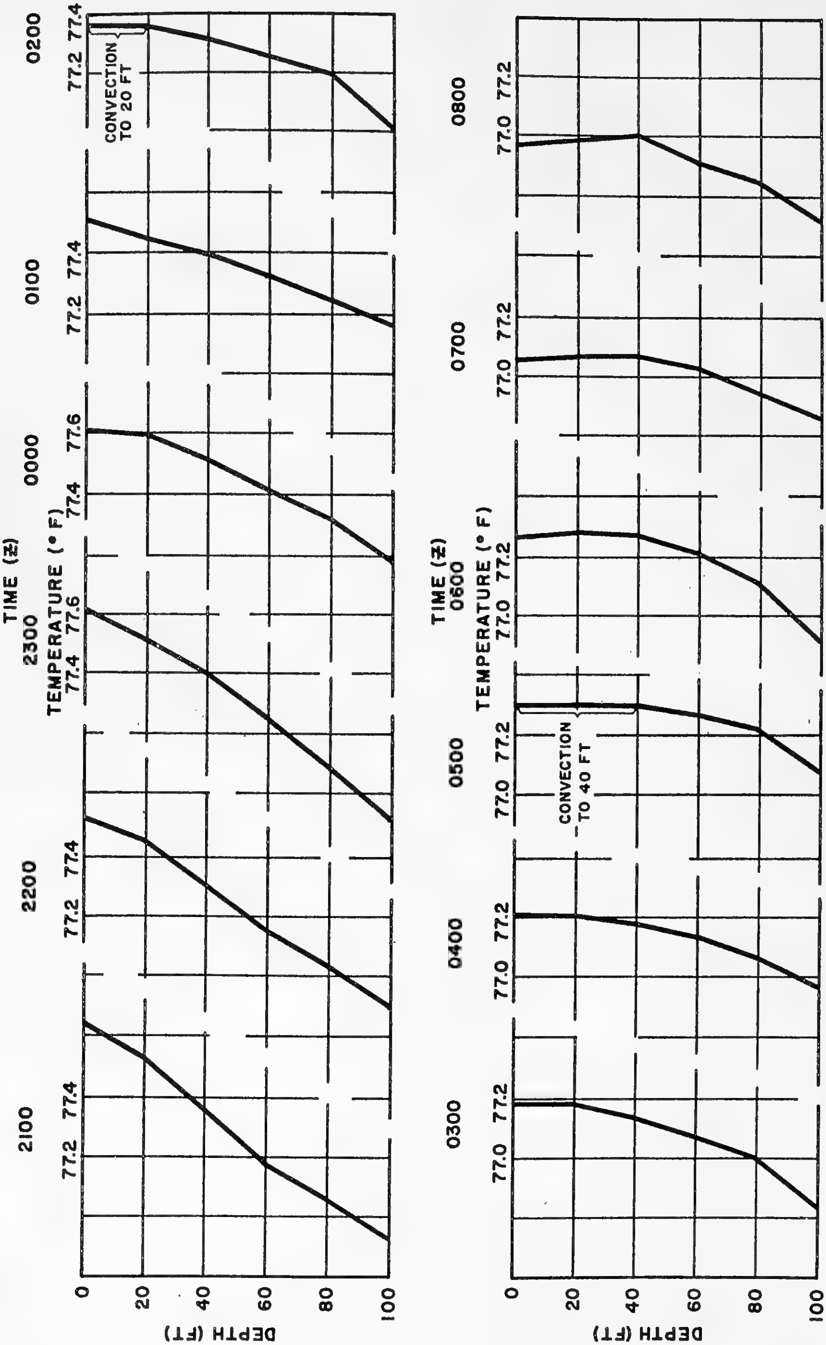


FIGURE 7 MEAN BT TRACES — SUNSET TO SUNRISE

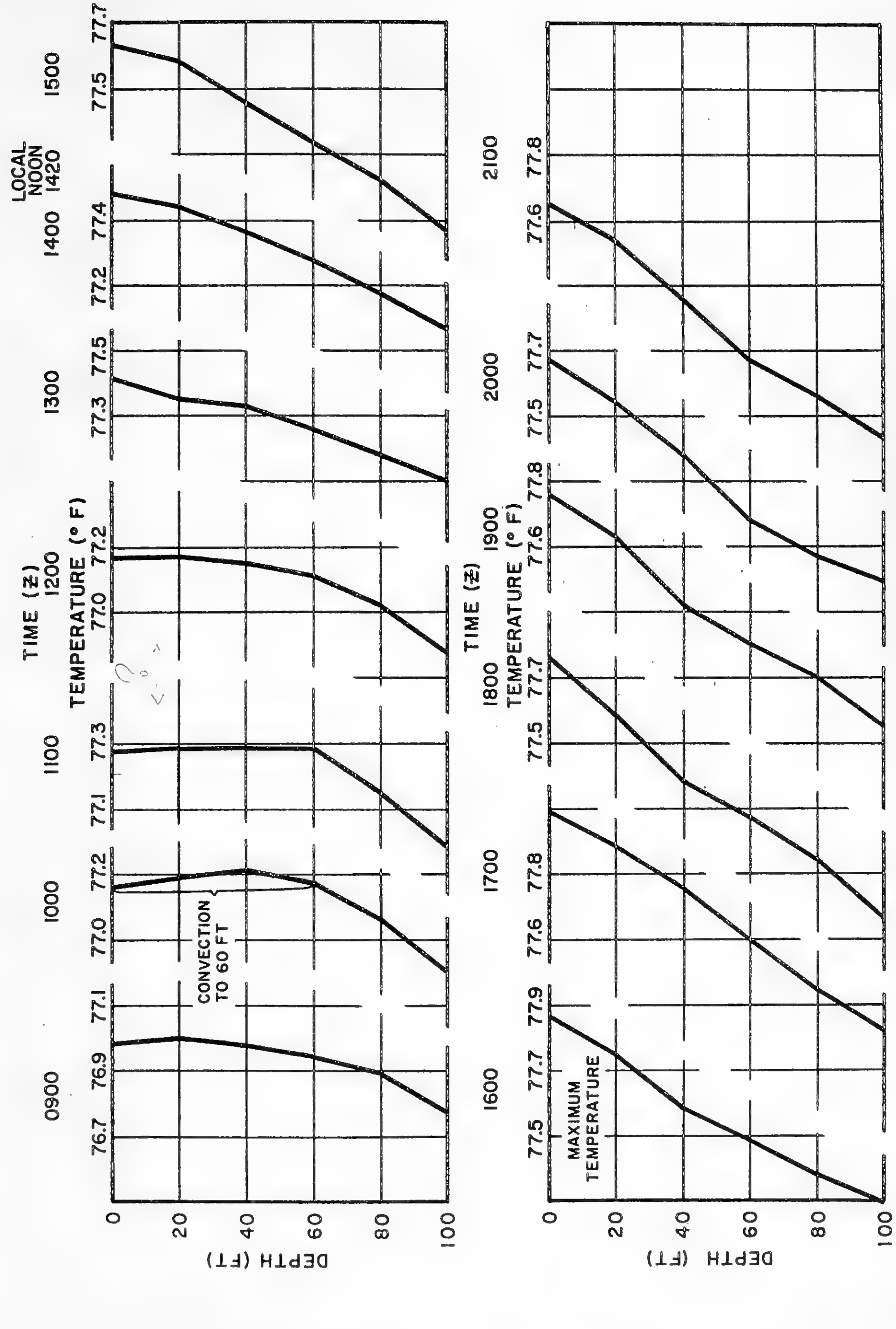


FIGURE 8 MEAN BT TRACES — SUNRISE TO SUNSET

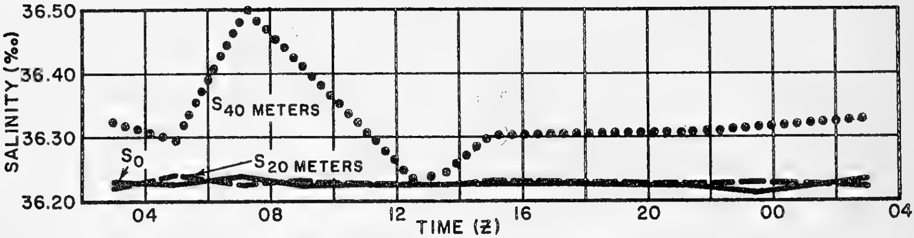


FIGURE 9 DIURNAL SALINITY CHANGES

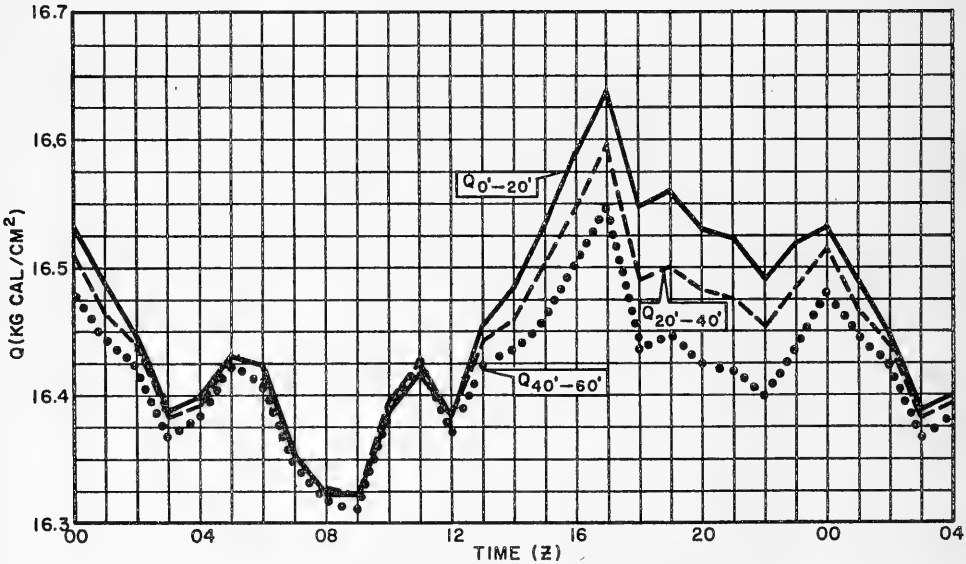


FIGURE 10 HEAT CONTENT (Q)

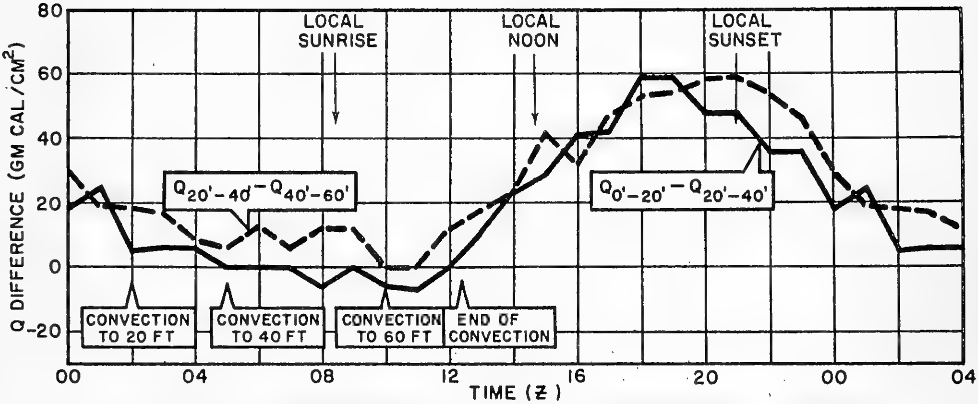


FIGURE 11 DIFFERENTIAL HEATING BETWEEN LAYERS

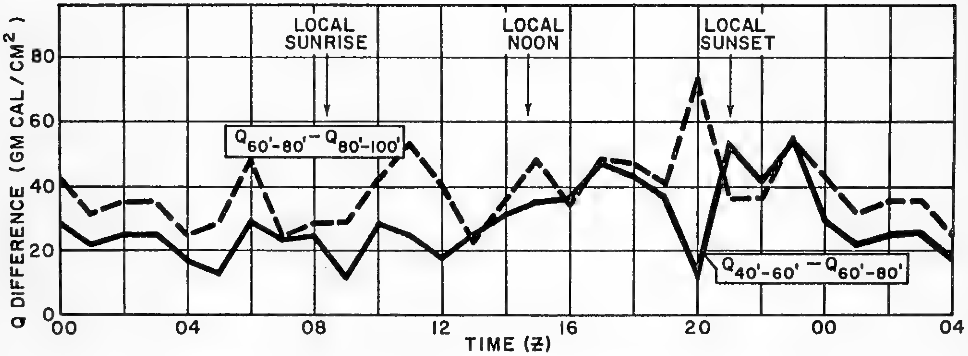


FIGURE 12 DIFFERENTIAL HEATING BELOW 40 FEET

the first layer to the third layer. In summation, the maximum heat differential between the first and second layers and between the second and third layers did not occur until 1800Z and 2000Z respectively, or nearly at sunset, although the maximum surface temperature was reached at 1700Z or 2.3 hours after local noon.

Figure 12 continues the study of differential heating of layers and shows that the differences of heat content between the third and fourth layers and between the fourth and fifth layers do not show much regularity. This indicates that the heating process is confined mainly to the upper 40 feet, although convection extends to 60 feet if differential heating alone is considered. In contrast, reversed logic leads to the conclusion that appreciable solar heating actually extends well below 100 feet as shown by the peaks in Figure 2. However, the amount of radiation absorbed in each layer is more constant than would be assumed from normal extinction coefficients (Sverdrup et al., 1942). As explained above, it must be remembered that Figure 2 is complicated by apparent internal wave action below a depth of 60 feet.

COEFFICIENT OF THERMAL CONDUCTIVITY

An inherent property of substances is equalization of temperature within the substance (assuming absence of outside influence). This property is thermal conductivity and occurs when thermal gradients exist in the substance. The coefficient of thermal conductivity for sea water is slightly smaller than that for fresh water, according to the Smithsonian Tables. The BT data described above may be used to estimate this coefficient.

Since the coefficient of thermal conductivity is given in units of calories per centimeter per second per degree centigrade, it is evident that the dimensions of these units are equivalent to the rate of change of the temperature gradient. If this rate of change can be approximated, a value of the coefficient can be determined. In terms of finite differences, the temperature difference between layers is proportional to the temperature gradient. The time change of the difference is the first differential, and the rate of change is the coefficient of thermal conductivity.

Sampling errors are minimized by use of fitted curves. Therefore a Fourier analysis (for the second harmonic) of the differences plotted in Figure 3 was performed by digital computer. The fitted curves are shown in Figure 13. Gradients within the layers are shown in Figure 14. Table 2 lists changes in temperature differences, from which the coefficient may be estimated. In Table 2, phase changes from positive to negative or differences of maximal differentials are about one hour between the 20- to 40-foot layer and the 40- to 60-foot layer. The 0- to 20-foot layer must be omitted because of wave action. As shown in Figure 14, temperature gradients in the upper two layers (0-20 and 20-40 feet) are in phase; however, wind mixing reduces the gradients in the 0- to 20-foot layer so that eddy conductivity and thermal conductivity cannot be distinguished.

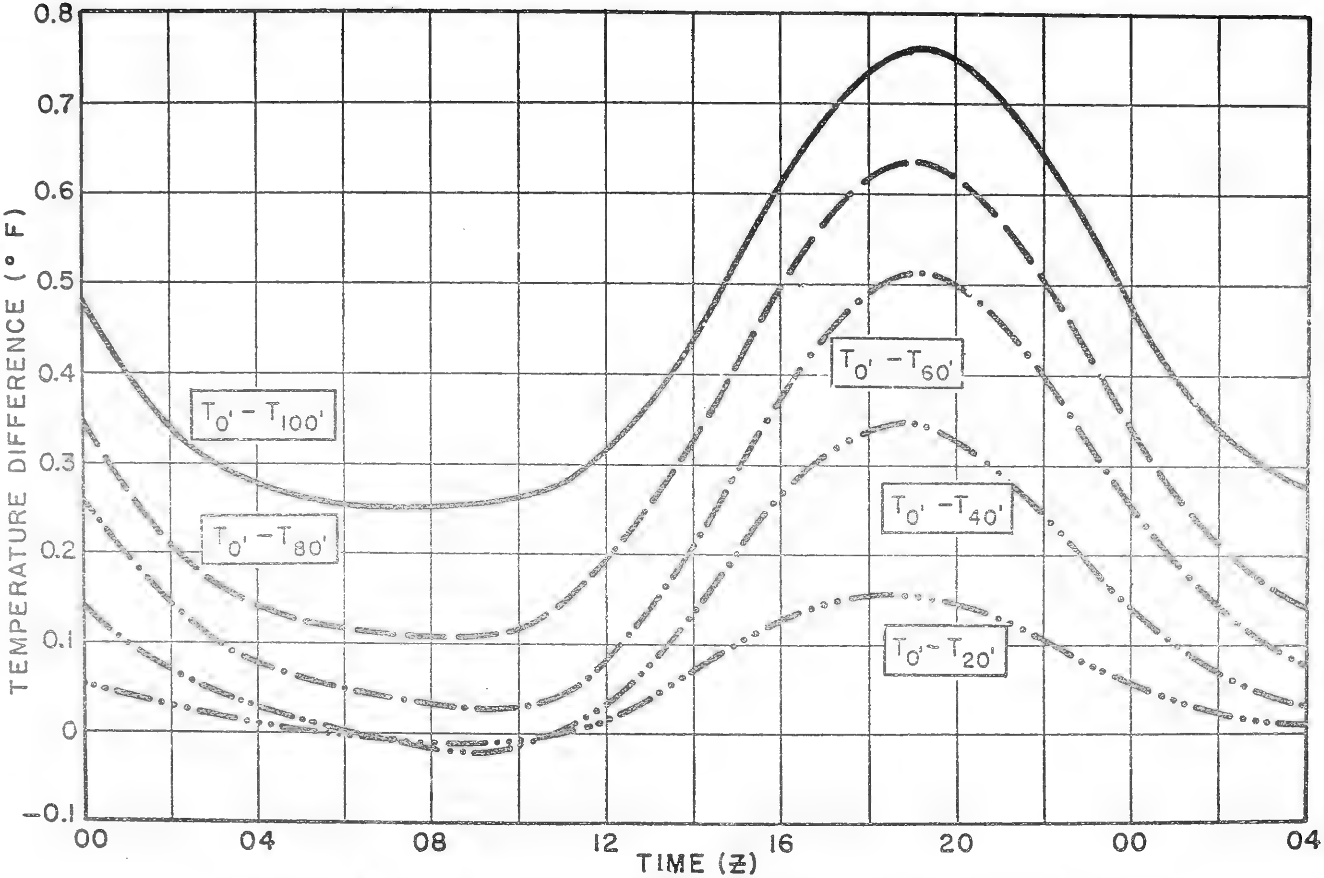
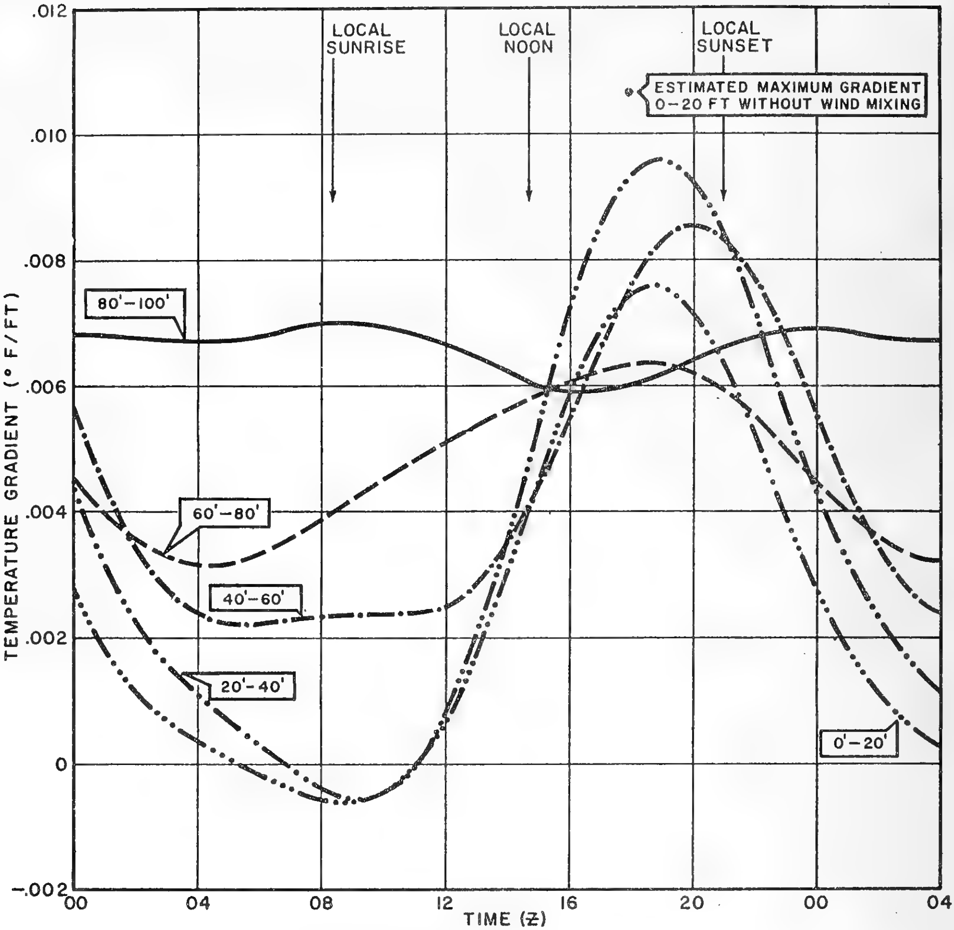


FIGURE 13 FITTED CURVES OF TEMPERATURE DIFFERENCE



NOTES (FIGURE 14)

INTERPRETATION OF INDIVIDUAL CURVES IS:

LAYER	INTERPRETATION
0'-20'	WIND MIXING AND HEATING
20'-40'	HEATING
40'-60'	HEATING
60'-80'	INTERNAL WAVES AND HEATING
80'-100'	STATIONARY INTERNAL WAVES

FIGURE 14 TIME CHANGES IN TEMPERATURE GRADIENTS

TABLE 2

Change in Temperature Differentials from Fitted Curves (° F)

Hour (Z)	0-20 ft	20-40 ft	40-60 ft	60-80 ft
1200-1300	.022	.026	.008	.005
1300-1400	.027	.032	.012	.006
1400-1500	.028	.035	.018	.004
1500-1600	.026	.033	.022	.004
1600-1700	.021	.028	.022	.004
1700-1800	.012	.018	.020	.001
1800-1900	.002	.006	.014	.000
1900-2000	-.008	-.007	.005	-.002
2000-2100	-.017	-.017	-.004	-.006
2100-2200	-.022	-.022	-.011	-.007
2200-2300	-.024	-.028	-.021	-.010
2300-0000	-.023	-.027	-.023	-.002

If the rate of phase difference is estimated to be 20 feet per hour, the amount of change may be estimated. The average absolute temperature differential change within the 20- to 40-foot layer in any given hour and within the 40- to 60-foot layer an hour later is .0073° F. Using a specific heat of .93 cal/gm/° C, the thermal conductivity coefficient is .00065 cal/cm/sec/° C. The figure of .00065 is considerably lower than that given in the Smithsonian Tables (.00143). Thus some fifty percent of thermal conductivity appears to be counterbalanced by turbulent mixing due to wave action. It should be noted that Table 2 includes only daylight hours during which convective mixing was absent, so that turbulent or mechanical mixing constitutes the only process for vertical heat transfer that is unaccounted for by this analysis.

VARIABILITY

In the discussion above, conclusions have been confined to the explanation of mean temperature and mean salinity changes in the upper layer of the ocean. However, as with all observations, there is much variability in the temperature readings from which the mean values are computed. The major sources of variation may be summarized as follows: (1) Instrumental error; that is, errors caused by faulty temperature and pressure elements in a bathythermograph. Such errors may be assumed constant for temperature and to increase slightly with depth as pressure increases. (2) Reading error, defined as the average difference between readings of the same BT trace by two different persons. (3) Interdiurnal variability; that is, day-to-day difference in temperature owing to either short- or long-period fluctuations such as tidal periods and seasonal effects, plus variability introduced by grouping the observations by hours. (4) Advection or horizontal movements of water of differing temperatures.

Although the actual values of these variations are not known with certainty, tentative values may be given. A study of scale error in BT's made by this Office in 1959 revealed an error of approximately 0.2° F. The reading error is estimated at about 0.1° F. The inter-diurnal variation is small, probably no more than 0.2° F, but is concentrated near the surface because of wave action. Thus, after allowing for these sources of variation, Table 3 shows that the major source of variation must be presumed to be advection.

TABLE 3

Hourly Standard Deviations of Temperature After Removal of Variations Other than Advection (° F)

Hour (Z)	Surface	20 ft	40 ft	60 ft	80 ft	100 ft
0000	.59	.69	.72	.83	.79	.91
0100	.57	.57	.61	.68	.77	.82
0200	.57	.58	.61	.63	.68	.73
0300	.59	.61	.63	.66	.70	.74
0400	.59	.59	.59	.61	.65	.68
0500	.65	.65	.64	.67	.69	.82
0600	.62	.61	.63	.63	.73	.88
0700	.45	.46	.46	.47	.51	.57
0800	.58	.57	.58	.61	.61	.63
0900	.58	.57	.56	.55	.52	.62
1000	.66	.68	.68	.69	.77	.86
1100	.69	.68	.69	.72	.82	.98
1200	.68	.69	.72	.75	.82	.92
1300	.69	.73	.74	.78	.86	.94
1400	.58	.60	.60	.65	.72	.81
1500	.58	.59	.58	.63	.73	.84
1600	.51	.46	.45	.61	.61	.72
1700	.58	.54	.55	.60	.75	.81
1800	.71	.65	.66	.68	.74	.81
1900	.59	.55	.62	.57	.76	.86
2000	.67	.65	.66	.78	.81	.83
2100	.75	.70	.67	.76	.82	.88
2200	.77	.77	.72	.73	.76	.83
2300	.77	.77	.72	.76	.73	.83

A standard deviation of 0.1° F is equivalent to 130 gm cal/cm^2 in a layer 20 feet thick. In Figure 3 it can be seen that the temperature gradient for the top 20 feet decreased from 0.1° to 0° F between 2300Z and 0200Z, or three hours, corresponding to a heat change of 22 gm cal/cm^2/hr. The gradient in the upper 40 feet also changed from 0.1° to 0° F between 0100Z and 0500Z, or four hours, a rate of change of 32 gm cal/cm^2/hr. Similarly the gradient in the top 60 feet was reduced to 0° F between 0300Z and 1000Z, or 7 hours, a rate of 28 gm cal/cm^2/hr. These calculations are summarized in Table 4. These values are very small compared to the advective variation which amounts to at least 590 gm cal/cm^2/hr for the smallest standard deviation in Table 3. However, the vertical changes are much more regular and also much better organized owing to the physical processes involved.

TABLE 4

Energy Involved in Convective Mixing

Hour (Z)	Depth of Convection	Energy (gm cal/cm^2/hr)
2300-0000	20 ft	22
0000-0100	20 ft	22
0100-0200	40 ft	54 (22 + 32)
0200-0300	40 ft	32
0300-0400	60 ft	60 (32 + 28)
0400-0500	60 ft	28
0500-0600	60 ft	28
0600-0700	60 ft	28
0700-0800	60 ft	28
0800-0900	60 ft	28
0900-1000	60 ft	28

SUMMARY

This study was undertaken for the purpose of estimating the numerical values of various physical processes involved in the diurnal cycle of heating and cooling in the upper layer of the ocean. Magnitude of the vertical processes, convection and surface heating, has been estimated with some degree of precision. However, the energy contributed by the major horizontal process of advection is much greater than that contributed by the vertical processes. In order to incorporate advection into the deductive and predictive procedures which are under development for the ASWEPS program, either a greater number of accurate, closely-spaced synoptic observations must be obtained, or thermal structure prediction must be confined to long time periods in which advection can be minimized. Otherwise, direct means of measuring advection must be devised.

REFERENCES

DEFANT, ALBERT. Physical Oceanography. New York, Pergamon Press, 1961. (2 vol). Vol. 1, p. 109-117.

GEIGER, RUDOLF. The Climate Near the Ground. Cambridge, Massachusetts, Harvard University Press, 1950. Chap. XV, p. 153-163.

LA FOND, E. C. Environmental Factors Affecting the Vertical Temperature of the Upper Layers of the Sea. Waltair, India, Andhra University Memoirs in Oceanography, 1954. Vol. 1, p. 94-101.

SVERDRUP, H. U., M. W. JOHNSON, and R. H. FLEMING. The Oceans. Englewood Cliffs, New Jersey, Prentice-Hall, 1942. P. 128-137.

U. S. Navy Hydrographic Office. Numerical Prediction of Short-Term Thermal Structure Changes at a Point, by Doyce B. Nix. H. O. Technical Report No. 130. January 1962. 20 p. (in press).

U. S. Navy Hydrographic Office. Effects of Weather Upon the Thermal Structure of the Ocean, by J. J. Schule, Jr. H. O. Misc. 15360. 1952. 81 p.

U. S. Naval Oceanographic Office.
DIURNAL TEMPERATURE CHANGES AT OCEAN STATION ECHO - SEPTEMBER 1959, by Edward L. Corton, June 1962. 21 p. including 14 figs. and 4 tables. (NAVOCEANO TR-132, ASWEPS REPORT No. 9)

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