AD-753 442

MILOCMED 1968: A DROGUE EXPERIMENT IN THE IONIAN SEA. PART I. THE TEMPERATURE TIME SERIES

Adolf Dahme, et al

SACLANT ASW Research Centre
La Spezia, Italy

15 October 1972

SACLANTCEN Technical Memorandum No. 181

AD753442

SACLANTCEN

Technical Memorandum No. 181

SACLANT ASW RESEARCH CENTRE

MILOCMED 1968: A DROGUE EXPERIMENT IN THE IONIAN SEA

PART I: THE TEMPERATURE TIME SERIES

by

ADOLF DAHME and ANDRE DE HAEN

15 OCTOBER 1972

NORTH ATLANTIC TREATY ORGANIZATION

Reproduced by
NATIONAL TECHNICAL INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

VIALE SAN BARTOLOMEO 400
I - 19026 - LA SPEZIA, ITALY

This document is released to a NATO Government at the direction of the SACLANTCEN subject to the following conditions:

1. The recipient NATO Government agrees to use its best endeavours to ensure that the information herein disclosed, whether or not it bears a security classification, is not dealt with in any manner (a) contrary to the intent of the provisions of the Charter of the Centre, or (b) prejudicial to the rights of the owner thereof to obtain patent, copyright, or other like statutory protection therefor.

2. If the technical information was originally released to the Centre by a NATO Government subject to restrictions clearly marked on this document the recipient NATO Government agrees to use its best endeavours to abide by the terms of the restrictions so imposed by the releasing Government.

SACLANTCEN

TECHNICAL MEMORANDUM NO. 181

NORTH ATLANTIC TREATY ORGANIZATION

SACLANT ASW RESEARCH CENTRE

Viale San Bartolomeo 400

I 19026 - La Spezia, Italy

MILOCMED 1968: A DROGUE EXPERIMENT IN THE IONIAN SEA

PART I: THE TEMPERATURE TIME SERIES

by

Adolf Dahme and André de Haen

Published

15 October 1972

APPROVED FOR DISTRIBUTION
(June 1972)

Ir M.W. van Batenburg
Director

Manuscript Completed:

15 March 1971

I b

TABLE OF CONTENTS

List of Figures

TABLE OF CONTENTS (Cont'd)

List of Figures (Cont'd)

MILOCMED 1968: A DROGUE EXPERIMENT IN THE IONIAN SEA

PART I: THE TEMPERATURE TIME SERIES

by

Adolf Dahme and André de Haen

ABSTRACT

During an oceanographic survey (MILOCMED 68) made in the Ionian Sea between 15 May and 5 June 1968, temperature profiles were obtained every three minutes by means of free-drifting, self-recording drogues equipped with 60 m long thermistor chains. The gathering and processing of two of these time series, one covering a period of 17 days and one a period of 4 days, are described. The results reported include an indication of an oceanographic front in the area that causes sharp horizontal changes in the temperature structure both above and below the thermocline. They also include information about the daily heating cycle of the near-surface water and about the effects of internal waves on the temperature structure within the thermocline.

INTRODUCTION

An oceanographic survey of an area approximately 100 miles east of Malta was made between 15 May and 5 June 1968 (MILOCMED 68) with the assistance of several nations. Part of the programme was a study of the diffusion of the surface water, made by tracking the drift of six drogues, which is described in a companion report (Ref. 1).

The present paper describes the temperature variations observed by arrays of 21 thermistors suspended beneath two of the drogues (ALPHA, FOXTROT) at fixed depths between 0.5 m and 60 m. (Unfortunately, the thermistor arrays attached to two other drogues malfunctioned and the data could not be meaningfully processed.) The period covered by drogue ALPHA extends from 1615Z 16 May to 1400Z 2 June and by drogue FOXTROT from 1448Z 16 May to 1515Z 20 May.

This report describes in some detail the techniques employed for the collection and processing of the temperature profile data; the main part of the report describes several remarkable temperature variations recorded as the drogues drifted through different water masses.

1. DATA COLLECTION

Figure 1 gives a simplified sketch of the drogues used to support the thermistor arrays. Each drogue had four 5 m^2 canvas-covered vanes (mounted axially at right angles to each other) to increase drag. A mast about 3 m high carried a radar reflector and a flashing light to facilitate tracking.

All the thermistors were electrically connected to outlets moulded at specified positions [see Table 1] on neoprene-insulated, concentric twin cable of 9 mm diameter. For the thermistors suspended below the drogue the cable was taped to a 3.2 mm diameter wire rope carrying a 60 kg weight. The cable for the shallower thermistors was taped to a nylon rope stretched along the side of the drogue. The error in geometrical distance of the thermistors from the design datum level (the sea surface) is believed to be less than $\pm$ 5 cm and, as the drogues had enough buoyancy to ride any waves more than a few metres long, this distance can be considered as the true depth of the thermistors beneath the free sea surface.

Each thermistor was housed in a small plastic case to increase its time constant to about two minutes, that is, 1/3 of the Nyquist period based on the sampling period of three minutes. This increased time constant also has the advantage of reducing the influence of wave motion, as it is much larger than the wave periods. Thus the variations in the temperature structure are integrated by the fact that the array closely follows the wave motion.

The scanning and recording procedures performed by equipment housed in the cylindrical body of the drogues were essentially those described in Ref. 2 and successfully used during previous surveys in the Strait of Gibraltar. All thermistors were scanned every three minutes, one whole scan being completed in 10 seconds.

The signals were recorded on tape for later processing by the computer ashore. An additional feature not available during previous cruises was that a small transmitter housed in the upper part of the drogue could transmit the signals present on the tape over distances of a few miles, thereby indicating whether the whole temperature recording system was working properly. The absolute accuracy of the complete system, including calibration, recording, computer transfer and processing, is estimated to be 0.1°C, but the relative accuracy between adjacent scans is probably better than 0.02°C.

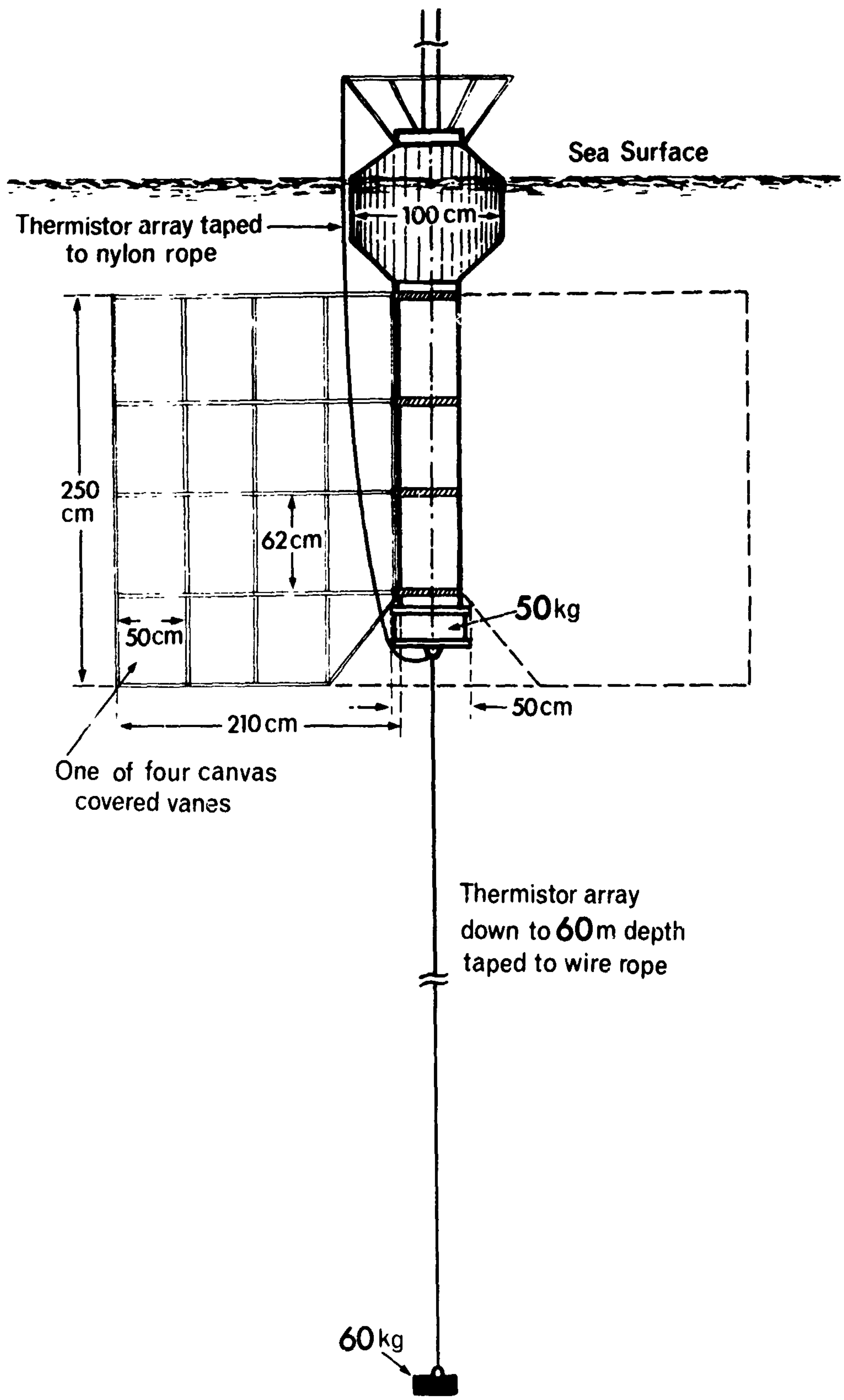
The tracks of the two drogues while useful data were being recorded are given in Fig. 2. Drogue ALPHA was launched at 1554Z on 16 May and by 1615Z its array started to make undisturbed temperature recordings. The drogue was partly lifted between 0900Z and 0954Z on 20 May for inspection, without changing its position or interrupting the electronic circuitry. At 0430Z on 23 May it was recovered for repairs to the canvas of the vanes. When it was relaunched on the same day at 0742Z it was placed approximately 10 n.mi west of its previous position so as to make it easier to track the two drogues, which had by the separated considerably. There were no further interruptions until it was recovered at 0800Z on 5 June. However, inspection of the data revealed that the battery power had dropped during the last days, causing a drift of the temperature data. Hence, only the data recorded until 1400Z on 2 June were considered good.

Drogue FOXTROT was launched approximately 5 n.mi south of Drogue ALPHA at 1348Z on 16 May and undisturbed recording started at 1448Z. The drogue was recovered for repair at 1518Z on 20 May. After relaunching at 1827Z on 20 May the drogue ceased to give useful data.

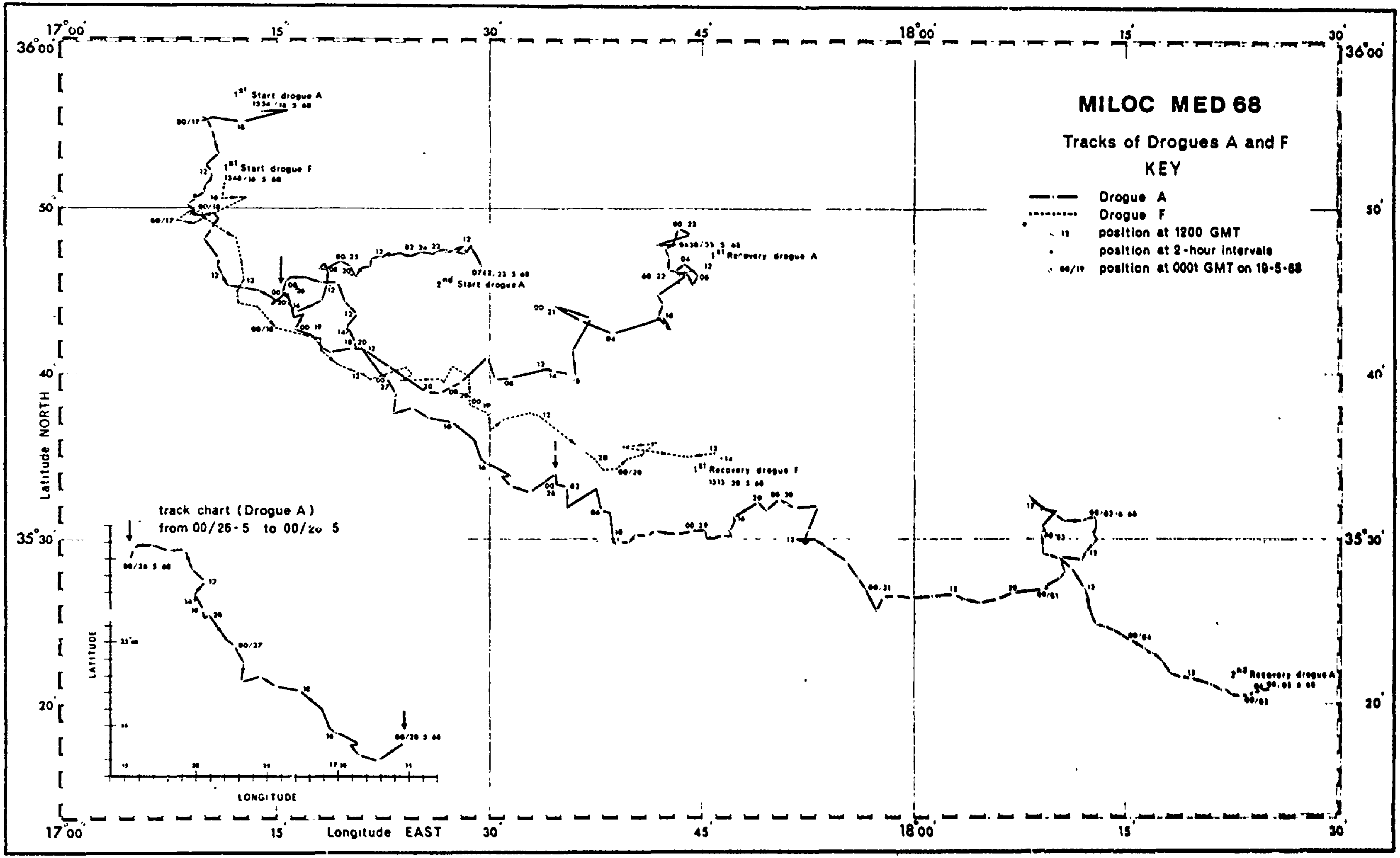
TABLE 1

DEPTHS OF THERMISTORS	
DROGUE ALPHA	DROGUE FOXTROT
0.50 m	0.50 m
1.25 m	1.25 m
2.25 m	2.00 m
3.25 m	2.75 m
4.00 m	3.25 m
5.00 m	4.00 m
6.00 m	5.00 m
7.00 m	6.00 m
8.00 m	7.00 m
9.00 m	8.00 m
10.00 m	9.00 m
12.00 m	10.00 m
14.00 m	12.00 m
16.00 m	14.00 m
18.00 m	18.00 m
22.00 m	22.00 m
28.00 m	28.00 m
34.00 m	34.00 m
40.00 m	40.00 m
50.00 m	50.00 m
60.00 m	60.00 m

DROGUE MILOC 1968



F.G. I TYPE OF DROGUE USED IN MILOCMED 68



7.1

FIG. 2 TRACK CHART OF DROGUE ALPHA AND DROGUE FOXTROT
(The track of Drogue ALPHA during 26-28 May is repeated in bottom left corner)

7.2

7.3

2. DATA PROCESSING

Before the recordings were converted from analogue to digital form and transferred to the computer, their quality was checked by displaying the data on an electrosensitive strip chart in the same form as it had been recorded on magnetic tape. This also permitted a check of the start and end of the undisturbed recording, the noise level, the regularity of the synchronization pulses, and the time marks.

The data were then processed by a general computer system for oceanographic data developed at SACLANTCEN, out of which the following sets of programs were used:

One program checks the homogeneity of the calibration points of the thermistor probes and calculates their deviation from the theoretical experimental curves; after any necessary adjustments another program calculates the coefficients of the functions representing the individual calibration curves.

The asynchronously-stored time intervals resulting from the transfer from the tapes are separated into individual scans. The successive time intervals are then referred to a common origin and assigned to their corresponding sensors. One auxiliary program checks this synchronization and another counts the cycles found between two fixed time marks in order to make sure that no scan has been lost, which would result in a shifted time scale for the rest of the analysis. The response times of the sensors are then introduced into their respective calibration equations and the corresponding temperatures are calculated.

The original recordings contain reference information that is transferred to successive computer tapes and used to detect incomplete, noisy or unsynchronized scans, which would result in errors in the calculated temperatures. If such a fault is present, part of the scan is usually incorrect. This part is then rejected by the program and replaced by a linear interpolation between the preceding and subsequent accepted values. These eliminated scans represented less than 1% of the total data reported here. The original record has a time mark instead of a temperature profile at every 80th scan, i.e. every 4 hours of real time; this missing scan is also replaced by an interpolation. To avoid an interruption of the time series the two large gaps (one of 1 hour and one of 3 hours) in the data from drogue ALPHA were filled by a series of temperature profiles linearly interpolated between the preceding and subsequent good scans.

The refined data were finally treated by specific programs that compute, list and plot the hourly and daily means and their corresponding standard deviations, as well as computing the total heat content of selected water columns and plotting the results against time.

3. RESULTS

3.1 Results derived from Daily Means

Tables 2 and 3 list the means and standard deviations of the 480 measurements recorded each day by drogues ALPHA and FOXTROT respectively. Because of the behaviour of the standard deviation — borne out by the hourly means — for the 3.25 m level of Drogue ALPHA, the values for this level from 17 to 26 May (given in parenthesis in Table 2) should be ignored.

The changes in the temperature structure during the survey can be seen more clearly from Figs. 3a and 4a, which display the daily mean temperatures at depths from 10 m to 60 m by 10 m increments (the levels at 20 m and 30 m are linearly interpolated from the adjacent level). The connecting lines serve solely to assist the eye to identify values belonging to the same level.

3.1.1 Drogue ALPHA

The most striking feature in the records of the mean temperature structure obtained from this drogue is the drastic changes between 26 and 28 May. In this period the temperature of the water at and below 20 m increased by about 2°C in the upper part of this stratum and by about 1°C in its lower part. This is demonstrated in a more familiar way in Fig. 5, which shows the temperature profiles in the form of bathythermograms. At the same time the temperature at the 10 m level decreased by nearly 1°C, partly through wind mixing. Unfortunately, the absence of salinity records for this period prevents a study of the change in the density structure and of the possible change in stability. The drogue's track on 26 and 27 May, which is repeated in the bottom left-hand corner of Fig. 2 for increased clarity, does not show any peculiarity that might help to explain this drastic change of the temperature structure, nor do the meteorological observations made aboard MARIA PAOLINA and

PLANET give a hint. At the end of the survey period the temperature tends to return to values obtained during the first part of the survey.

An idea of the mean temperature gradient in the surface layer above the thermocline is given by Fig. 3b, which shows the daily mean temperatures at 0.5 m, 5 m, 10 m and 15 m (the last being linearly interpolated from the 14 m and 16 m levels). During the first nine days there was a general heating at these levels, associated with an increasing temperature gradient. An exception was observed at the 16 m level on 20 May when it was apparently affected by an exceptionally large internal wave. The drastic changes at the lower levels on 27 and 28 May are reflected at the upper levels, but in the opposite sense: the temperature at 0.5 m depth decreased during these days by approximately 2°C. On these and the following two days the water at the four levels shown in Fig. 3b appears well mixed, which is confirmed by the standard deviations of the temperatures at the 0.5 m, 5 m and 10 m levels recorded on Fig. 3c. A considerable temperature gradient again developed on 1 June.

In Table 2b, the maximum and minimum values of the standard deviations of the temperatures are emphasized by circles. The depth of the maximum value, approximately indicating the depth where internal waves are most active (in as much as they produce the largest temperature variations) is constantly at 18 m until 26 May, and descends to 40 m during 27 May, concurrently with the change observed in Fig. 3a. It then ascends to 22 m during the last three days. The depth of the minimum standard deviation is more variable, the biggest change again occurring between 26 and 27 May. As previously indicated, the standard deviation is also a useful tool for investigating how homogeneous the different levels were or how well mixed the layer above the thermocline was; on 28 May, for example, the layer was particularly well mixed.

3.1.2 Drogue FOXTROT

Unfortunately the records of Drogue FOXTROT are short. They will therefore be used mainly for a study of the differences in the temperature structure at the different positions of the two drogues during the period of 17–19 May.

3.1.3 Differences of the Temperature Structure at the Positions of Drogue ALPHA and Drogue FOXTROT

Figures 6a, b and c compare the temperature structures (based on daily means) at the positions of the two drogues on 17, 18 and 19 May respectively and Table 4 lists the actual differences in temperature at each depth.

It is seen that, whereas there was little difference between the temperature profiles on 17 May [Fig. 6a] — in fact they were remarkably similar at depths below 25 m — there were differences on 18 and 19 May [Figs. 6b and 6c]. One is tempted to assign these differences to the increasing distance between the two drogues, as recorded in Table 5, which lists the distances every two hours (taken from the track chart of Fig. 2) together with the calculated daily average. At levels within the thermocline the temperature differences between the two drogues cannot properly be compared, because here the temperature gradients are stronger and therefore the influence of internal waves appears greater. In the survey area this might be assumed to occur at the four depths of 14 m, 18 m, 22 m and 28 m marked on Table 4. Above the thermocline, the picture is not uniform, as is demonstrated by Figs. 7a and 7b, based on Tables 4 and 5. For depths between the surface and 7 m, Fig. 7a suggests that on 17 and 18 May the two drogues stayed in more or less the same water mass but that on 19 May one drogue passed a boundary or a front. At greater depths, but still above the thermocline [Fig. 7b], no certain conclusion can be drawn. Below the thermocline [Fig. 7c] it appears that a front may have appeared between the two drogues on 18 May and remained there on 19 May.

Taking the geographical positions, and not the distances, as the determining factors, one observes from the track chart [Fig. 2] that nearly the same area was crossed by Drogue FOXTROT on 17 May as by Drogue ALPHA on 18 May. The same happened on the following days: an area crossed by Drogue FOXTROT on 18 May was crossed by Drogue ALPHA on 19 May. The temperature profiles for these two areas are plotted in Figs. 6d and 6e and it is seen that in both areas the temperature structure changed from one day to the other. However, as revealed by Figs. 6f and 6g, neither drogue recorded a change in the temperature structure beneath the thermocline on the two consecutive days. (Because the temperature structures above the thermocline are also influenced by the changing meteorological conditions they cannot be directly compared.) It can therefore be concluded that the boundary between the two water masses located beneath the thermocline and between the two drogues moved eastwards during 18 and 19 May.

It is noted that when Drogue ALPHA passed between 0 and 4 n.mi south of the same area on 27 and 28 May the water beneath the thermocline was considerably warmer [Fig. 3a].

3.2 Results Derived from Hourly Means

Figures 8 and 9 present graphically, as a function of time, the means and standard deviations of the 20 measurements recorded each hour by Drogues ALPHA and FOXTROT respectively.

The daily heating cycle within the surface layer is clearly demonstrated, its effect being normally confined to about the upper 8 m. Only when strong winds prevailed throughout the day, as on 20, 21 and 20 May, was the penetration deeper, whereas on calm days the penetration was less. The sharp peaks in the very near-surface layer on 25 May and 1 June were associated with calm weather at midday. The drastic changes on 26 and 27 May are easily recognizable: a decrease of the temperature in the surface layer is accompanied by an increase of the temperature below the thermocline. At the same time the "layer depth", i.e. the top of the thermocline, increases from about 14 m or 15 m to more than 18 m.

The strong oscillations of the temperature around depths of 22 m are attributed to internal waves. The thermal unrest extends, but to a lesser degree, to the region below the thermocline as a consequence of the temperature gradients still present in this stratum. Note that no changes in the temperature structure occurred when Drogue ALPHA was relaunched on the morning of 23 May at a position 10 n.mi west of its previous position.

Figure 10 shows the heat content, H, in excess of 17°C of a water column of 1 cm^2 cross-section between the surface and the indicated depths Z_c, computed as

$$H = \rho . c_p \int_o^{Z_c} (T-17)\,dz,$$

where

ρ = specific gravity of the water.

c_p = specific heat of the water under constant pressure.

T = temperature at depth z.

The general heating occurring during the periods 17 to 25 May (the first part of the 0-14 m curve indicates a daily average net heat gain of 200 cal/cm^2 for the 14 m deep water column during the first ten days of the survey) and 28 May to 1 June is clearly seen. On 26 and 27 May the drogue entered cooler surface water and there was a great apparent loss of heat. Another loss of heat started on 2 June.

TABLE 2a

Daily Mean Temperatures (°C) Computed from the Records of Drogue ALPHA

Depth m	May 1965: 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	June: 1
0.50	19.007	20.177	20.418	20.556	20.571	20.780	20.934	21.590	21.973	21.467	20.678	20.322	20.503	20.908	20.490	21.256
1.25	19.078	20.114	20.800	20.502	20.578	20.737	20.829	21.518	21.736	21.452	20.681	20.323	20.500	20.900	20.078	21.107
2.25	19.991	20.179	20.481	20.508	20.577	20.739	20.800	21.154	21.600	21.467	20.677	20.305	20.570	20.790	20.970	21.038
3.25	(19.985)	(20.123)	(20.387)	(20.320)	(20.574)	(20.660)	(20.681)	(20.933)	(21.252)	(21.331)	20.640	20.570	20.612	20.918	20.096	21.683
4.00	19.952	20.016	20.330	20.533	20.508	20.700	20.832	20.990	21.435	21.468	20.703	20.321	20.621	20.924	21.003	21.024
5.00	19.985	20.210	20.250	20.522	20.506	20.615	20.791	20.911	21.233	21.450	20.710	20.327	20.623	20.911	20.647	20.960
6.00	19.960	20.055	20.190	20.464	20.530	20.416	20.731	20.970	21.026	21.384	20.656	20.300	20.606	20.770	20.958	20.012
7.00	19.987	20.093	20.201	20.420	20.519	20.444	20.632	20.563	20.934	21.323	20.664	20.270	20.570	20.740	20.912	20.950
8.00	19.905	20.071	20.140	20.382	20.507	20.443	20.460	20.565	20.910	21.253	20.601	20.303	20.609	20.791	20.925	20.970
9.00	19.937	20.000	20.112	20.330	20.497	20.480	20.678	20.343	20.551	21.220	20.609	20.308	20.620	20.790	20.910	20.855
10.00	19.950	20.055	20.107	20.260	20.461	20.435	20.630	20.920	20.544	21.170	20.647	20.301	20.613	20.795	20.906	20.866
12.00	19.944	20.680	20.073	19.955	20.375	20.764	20.565	20.735	20.722	20.955	20.012	20.223	20.535	20.725	20.705	20.755
14.00	19.875	20.019	20.006	19.680	20.261	20.370	20.315	20.432	20.063	20.512	20.616	20.249	20.576	20.771	29.922	20.759
16.00	19.614	20.043	19.925	19.337	19.952	19.915	20.470	20.115	20.273	20.453	20.548	20.174	20.456	20.660	20.690	20.582
18.00	18.314	19.096	19.301	18.307	18.921	18.791	18.610	18.930	19.035	19.696	20.374	20.220	20.525	20.603	20.651	20.656
22.00	17.216	17.456	17.755	17.420	17.328	17.414	17.459	17.470	17.442	18.223	19.519	20.190	20.024	20.030	20.148	19.212
26.00	16.910	17.033	17.000	16.606	16.719	16.932	16.552	16.561	16.954	17.137	18.198	19.435	18.807	18.865	18.605	17.574
34.00	16.519	16.731	16.715	16.456	16.339	16.006	16.460	16.701	16.455	16.603	17.260	18.300	17.410	17.547	17.511	16.926
40.00	16.186	16.365	16.365	16.050	15.944	15.975	16.042	15.054	15.976	16.007	16.567	17.444	17.020	17.654	17.234	16.606
50.00	15.627	15.904	15.960	15.547	15.458	15.496	15.547	15.471	15.493	15.551	16.152	16.696	16.505	16.454	16.051	15.955
60.00	15.301	15.517	15.513	15.209	15.191	15.172	15.225	15.164	15.194	15.277	15.947	16.175	15.951	15.551	16.053	15.522

TABLE 2b

Standard Deviations (°C) of the Temperatures Recorded by Drogue ALPHA for Periods of One Day

Depth m	May 1965: 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	June: 1
0.50	0.067	0.125	0.234	0.174	0.133	0.268	0.254	0.590	0.350	0.133	0.290	0.075	0.191	0.135	0.142	0.459
1.25	0.067	0.125	0.226	0.173	0.120	0.255	0.251	0.556	0.349	0.133	0.290	0.075	0.101	0.133	0.130	0.217
2.25	0.064	0.124	0.221	0.172	0.125	0.255	0.245	0.354	0.340	0.136	0.290	0.074	0.101	0.132	0.135	0.196
3.25	(0.166)	(0.132)	(0.223)	(0.419)	(0.137)	(0.375)	(0.445)	(0.523)	(0.603)	(0.406)	0.290	0.077	0.101	0.132	0.135	0.163
4.00	0.066	0.124	0.207	0.174	0.126	0.250	0.137	0.224	0.414	0.170	0.300	0.079	0.101	0.130	0.120	0.139
5.00	0.060	0.115	0.172	0.174	0.111	0.100	0.009	0.112	0.343	0.119	0.297	0.076	0.101	0.121	[illegible]	0.114
6.00	0.059	0.116	0.137	0.192	0.067	0.107	0.087	0.079	0.204	0.135	0.297	0.074	0.100	0.104	0.069	0.079
7.00	0.055	0.102	0.102	0.201	0.052	0.049	0.002	0.066	0.110	0.162	0.296	0.070	0.190	0.004	0.050	0.047
8.00	0.055	0.097	0.060	0.214	0.071	0.026	0.001	0.059	0.057	0.201	0.295	0.066	0.100	0.060	0.061	0.035
9.00	0.054	0.090	0.030	0.200	0.061	0.023	0.055	0.056	0.085	0.220	[illegible]	0.065	0.190	0.050	0.044	0.033
10.00	0.054	0.097	0.028	0.208	0.003	0.038	0.087	0.056	0.001	0.244	0.297	0.060	0.16[illegible]	0.066	0.039	0.030
12.00	0.051	0.079	0.055	0.266	0.[illegible]54	0.019	0.213	0.088	0.138	0.242	0.293	0.056	0.192	[illegible]62	0.037	0.050
14.00	0.165	0.059	0.148	0.303	0.126	0.071	0.454	0.517	0.496	0.275	0.261	0.050	0.177	0.061	.064	0.140
16.00	0.573	0.314	0.313	0.310	0.333	0.506	0.441	0.567	0.308	0.372	0.28[illegible]	0.055	0.144	0.000	0.006	0.127
18.00	0.557	0.792	0.606	0.596	0.716	0.812	0.655	0.037	0.558	1.004	0.280	0.058	0.110	0.210	0.192	0.325
22.00	0.176	0.473	0.345	0.315	0.236	0.228	0.268	0.244	0.519	0.885	0.402	0.160	0.444	0.476	0.461	0.703
26.00	0.115	0.171	0.161	0.115	0.160	.156	0.115	0.197	0.207	0.270	0.586	0.338	0.665	0.436	0.426	0.343
34.00	0.118	0.130	0.142	0.151	0.178	0.140	0.110	0.170	0.187	0.241	0.717	0.280	0.596	0.260	0.251	0.302
40.00	0.121	0.161	0.153	0.106	0.164	0.144	0.120	0.149	0.153	0.278	0.978	0.157	0.405	0.222	0.240	0.194
50.00	0.101	0.134	0.160	0.144	0.066	0.065	0.111	0.083	0.073	0.186	0.567	0.125	0.256	0.206	0.17[illegible]	0.160
60.00	0.118	0.105	0.115	0.132	0.054	0.057	0.060	0.060	0.054	0.153	0.262	0.105	0.144	0.197	0.205	0.194

TABLE 3a

Daily Mean Temperatures (°C)
as Computed from the records of Drogue FOXTROT

Depth m	17	18	19
0.50	20.018	20.124	20.308
1.25	19.960	20.042	20.231
2.00	19.965	20.069	20.228
3.25	19.957	20.056	20.211
4.00	19.982	20.082	20.226
5.00	19.930	20.014	20.105
6.00	19.947	20.030	20.051
7.00	19.887	19.982	19.942
8.00	19.954	20.171	20.178
9.00	19.788	19.934	19.881
10.00	19.730	19.894	19.868
12.00	19.638	19.800	19.868
14.00	19.571	19.706	19.830
18.00	18.809	18.878	19.318
22.00	17.550	17.527	18.380
28.00	16.833	16.875	16.986
34.00	16.513	16.501	16.537
40.00	16.114	16.013	16.037
50.00	15.626	15.486	15.498
60.00	15.365	15.210	15.206

TABLE 3b

Standard Deviations (°C) of the Temperatures

Recorded by Drogue FOXTROT for Periods of One Day

Depth m	17	18	19
0.50	0.118	0.149	0.264
1.25	0.115	0.414	0.259
2.00	0.127	0.172	0.264
3.25	0.116	0.143	0.249
4.00	0.116	0.143	0.246
5.00	0.112	0.129	0.227
6.00	0.114	0.115	0.189
7.00	0.129	0.104	0.121
8.00	0.191	0.105	0.053
9.00	0.181	0.073	0.023
10.00	0.178	0.072	0.019
12.00	0.136	0.119	0.048
14.00	0.192	0.184	0.151
18.00	0.564	0.618	0.331
22.00	0.420	0.412	0.702
28.00	0.201	0.170	0.397
34.00	0.143	0.142	0.238
40.00	0.137	0.130	0.189
50.00	0.155	0.156	0.123
60.00	0.126	0.138	0.108

TABLE 4

Differences (°C) Between the Temperature Recorded at Drogue ALPHA and the Temperature at Drogue FOXTROT for the Same Depths

Depth m	17	18	19	
0.50	- 0.051	- 0.011	+ 0.106	
1.25	+ 0.018	+ 0.072	+ 0.178	
4.00	- 0.030	+ 0.016	+ 0.110	
5.00	+ 0.055	+ 0.102	+ 0.175	
6.00	+ 0.013	+ 0.055	+ 0.145	
7.00	+ 0.100	+ 0.111	+ 0.219	
8.00	+ 0.011	- 0.100	- 0.048	
9.00	+ 0.169	+ 0.126	+ 0.231	
10.00	+ 0.229	+ 0.164	+ 0.239	
12.00	+ 0.306	+ 0.240	+ 0.205	
14.00	+ 0.304	+ 0.312	+ 0.178	thermocline
18.00	- 0.495	+ 0.526	+ 0.073	
22.00	- 0.334	+ 0.129	- 0.625	
28.00	- 0.023	+ 0.158	+ 0.054	
34.00	+ 0.003	+ 0.230	+ 0.178	
40.00	+ 0.032	+ 0.352	+ 0.311	
50.00	+ 0.001	+ 0.412	+ 0.362	
60.00	+ 0.026	+ 0.307	+ 0.307	

TABLE 5

Distances apart (n.mi) of Drogue ALPHA and Drogue FOXTROT at different times

Hour GMT	16	17	18	19	20
0	-	6.3	8.3	11.1	10.9
2	-	5.6	9.1	11.1	10.7
4	-	5.6	9.1	10.7	10.7
6	-	5.5	9.7	10.6	10.0
8	-	5.2	9.3	10.7	7.9
10	-	6.7	9.8	11.2	10.7
12	-	6.7	10.1	10.7	11.0
14	-	6.6	9.3	11.4	11.0
16	6.5	7.0	8.7	11.4	-
18	4.6	7.1	10.4	10.6	-
20	5.5	7.3	9.6	10.6	-
22	6.3	7.5	10.3	10.6	-
mean	-	6.3	9.5	10.9	-

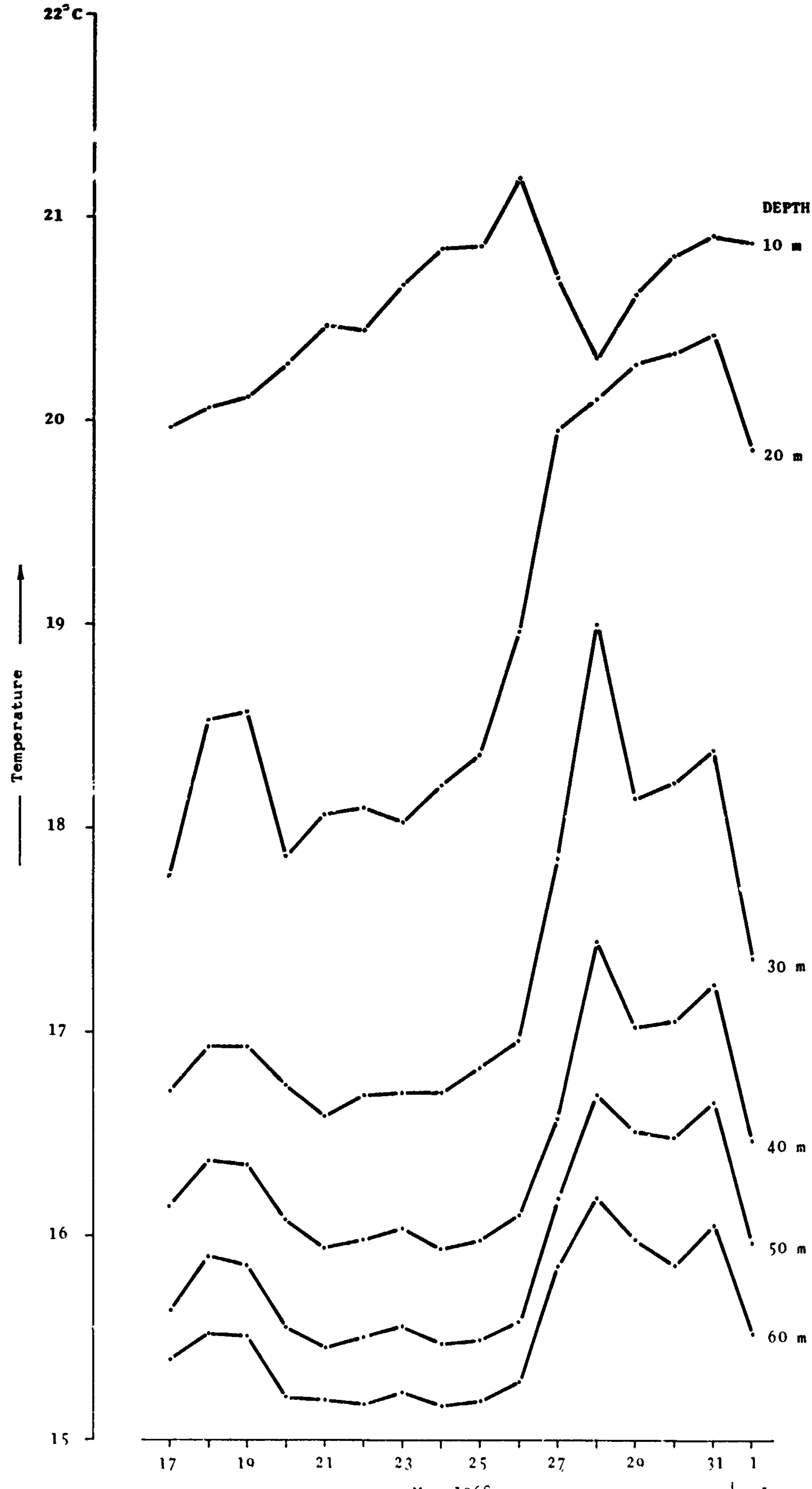


FIG. 3a DAILY MEAN TEMPERATURES AT SELECTED DEPTHS: DROGUE ALPHA

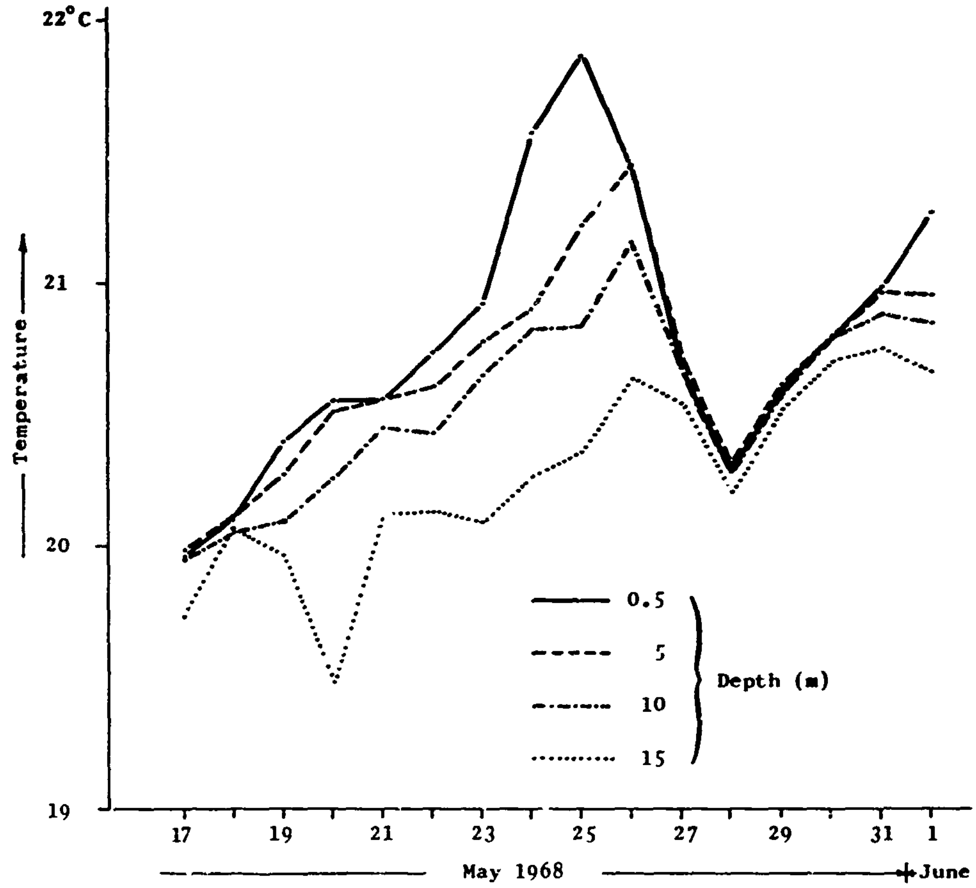


FIG. 3b DAILY MEAN TEMPERATURES IN THE UPPER 15 m: DROGUE ALPHA

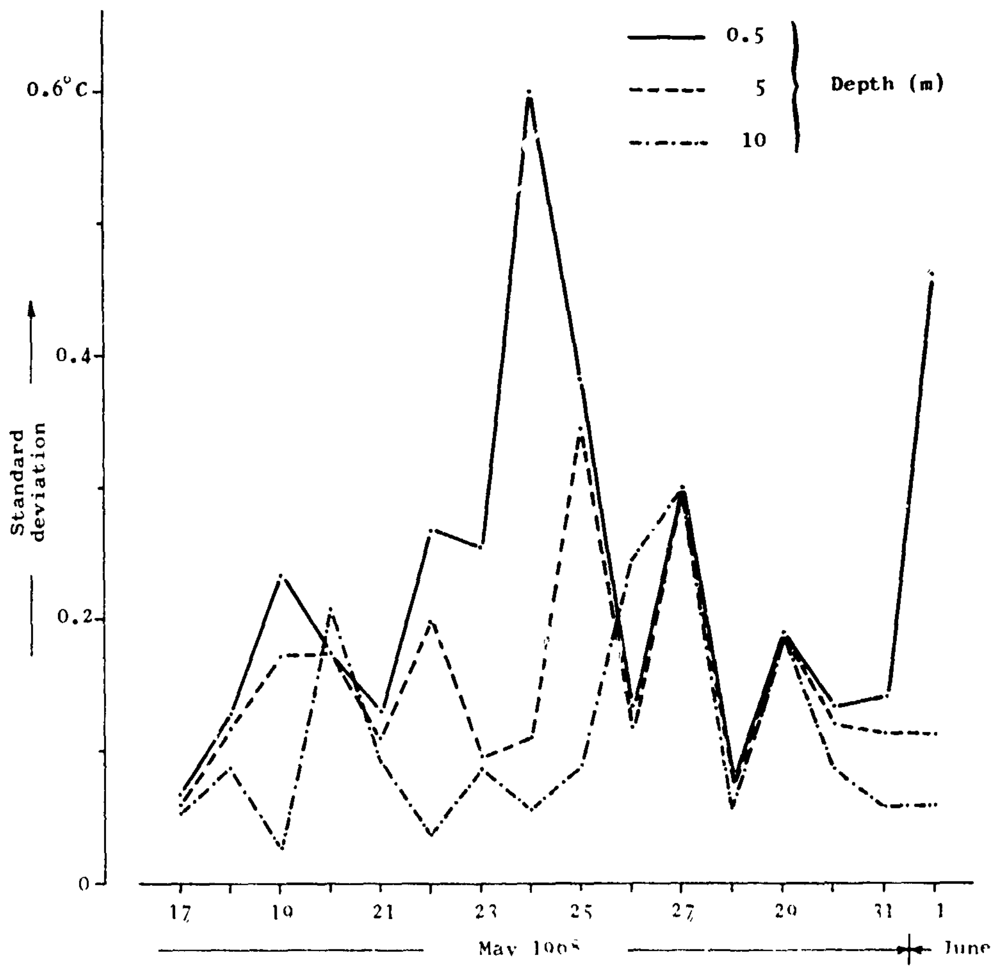


FIG. 3c STANDARD DEVIATIONS OF TEMPERATURES IN THE UPPER 10 m (1-day periods): DROGUE ALPHA

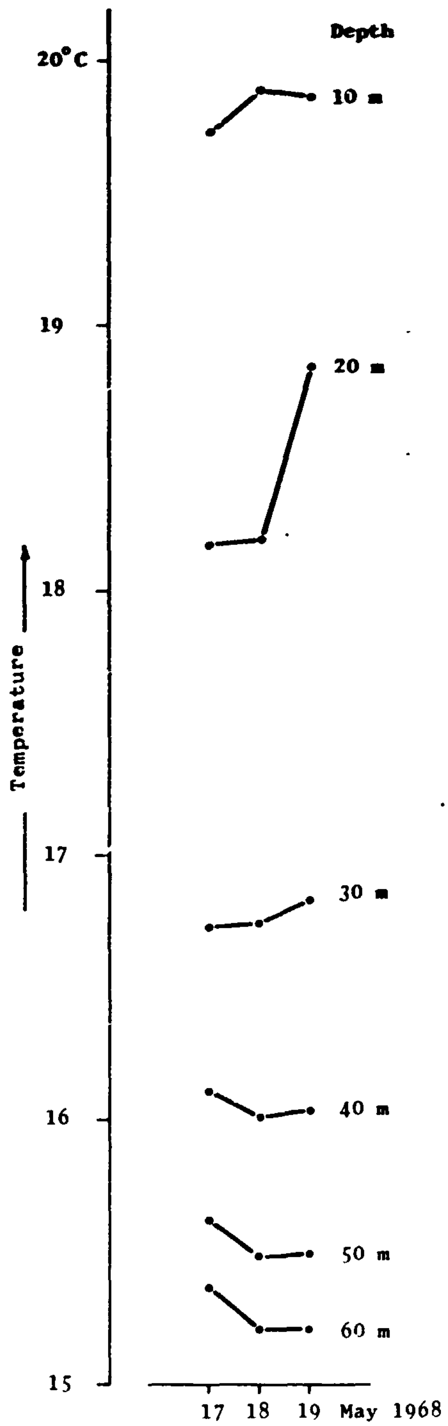


FIG. 4a DAILY MEAN TEMPERATURES AT SELECTED DEPTHS: DROGUE FOXTROT

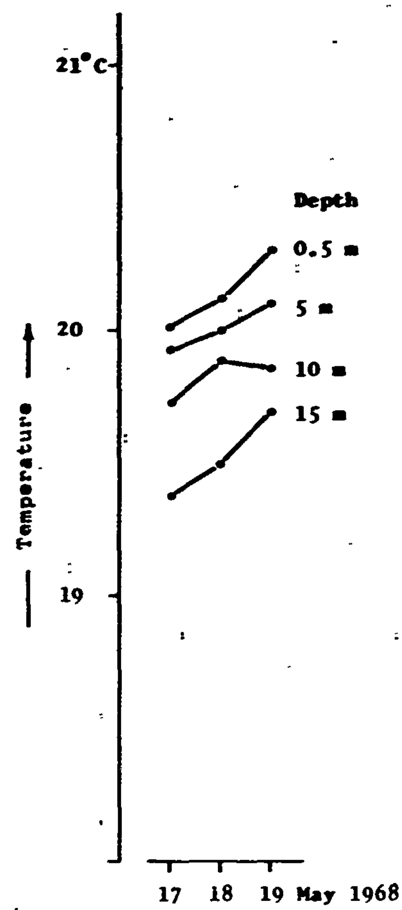


FIG. 4b DAILY MEAN TEMPERATURES IN THE UPPER 15 m: DROGUE FOXTROT

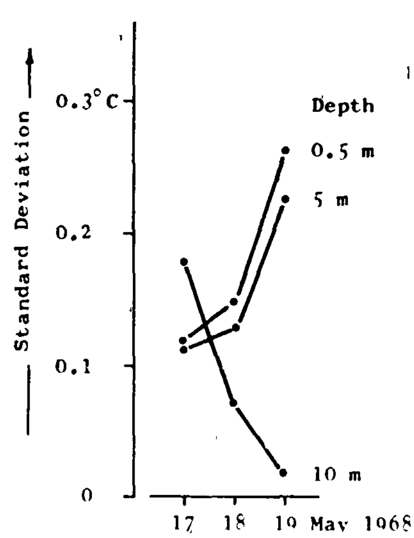


FIG. 4c STANDARD DEVIATIONS OF TEMPERATURES IN THE UPPER 10 m (1-day periods): DROGUE FOXTROT

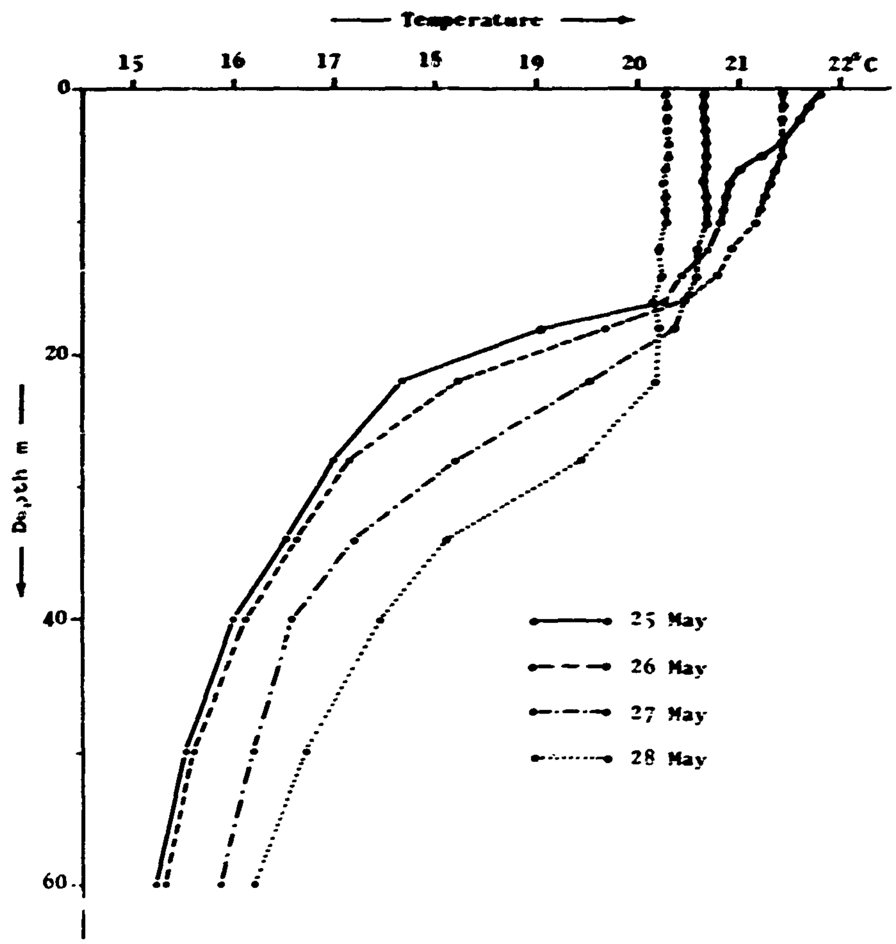


FIG. 5 TEMPERATURE PROFILES 25–28 MAY 1968, BASED ON DAILY MEANS RECORDED BY DROGUE ALPHA

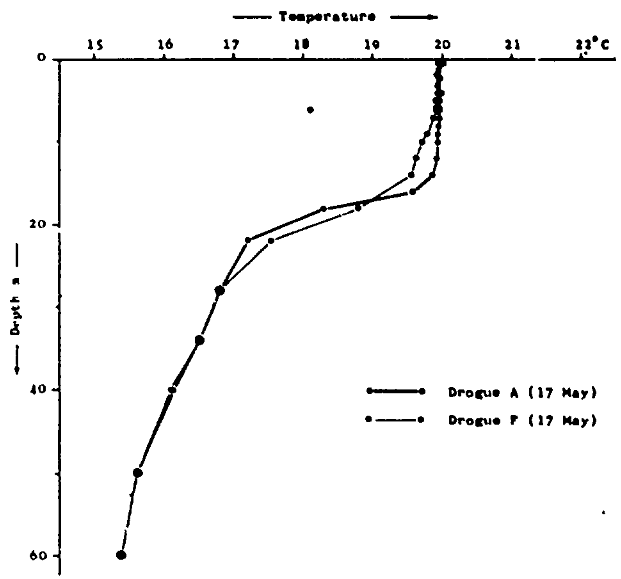


FIG. 6a TEMPERATURE PROFILES OF DROGUE ALPHA AND DROGUE FOXTROT, 17 MAY 1968

2.4·1

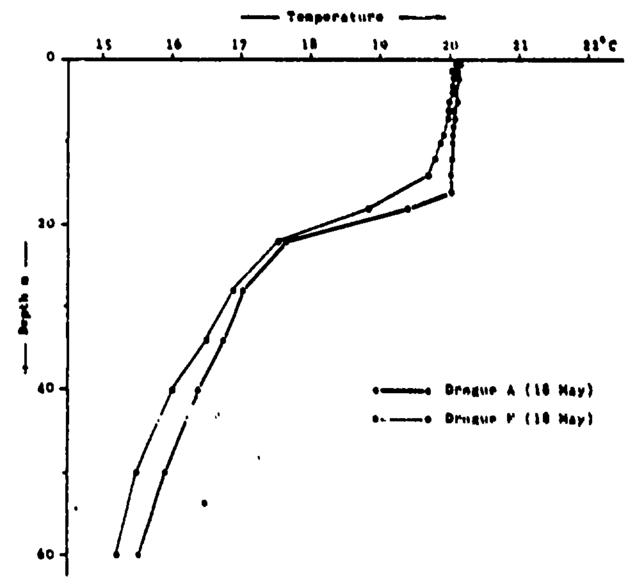


FIG. 6b TEMPERATURE PROFILES OF DPOGUE ALPHA AND DROGUE FOXTROT, 18 MAY 1968

24·2

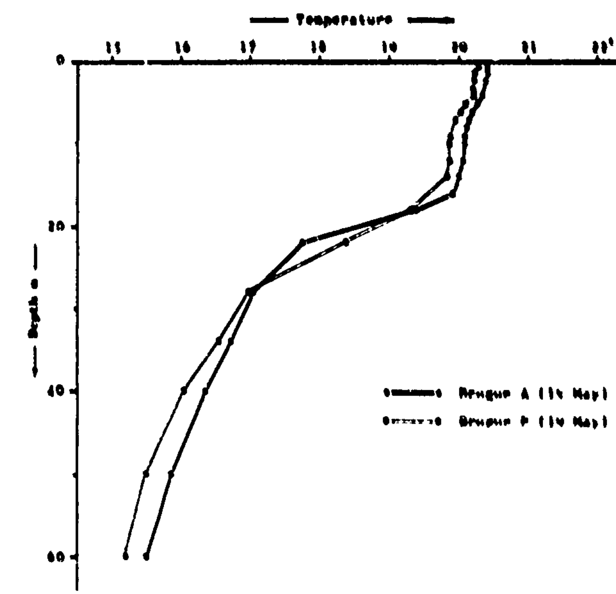


FIG. 6c TEMPERATURE PROFILES OF DROGUE ALPHA AND DROGUE FOXTROT, 19 MAY 1968

24·3

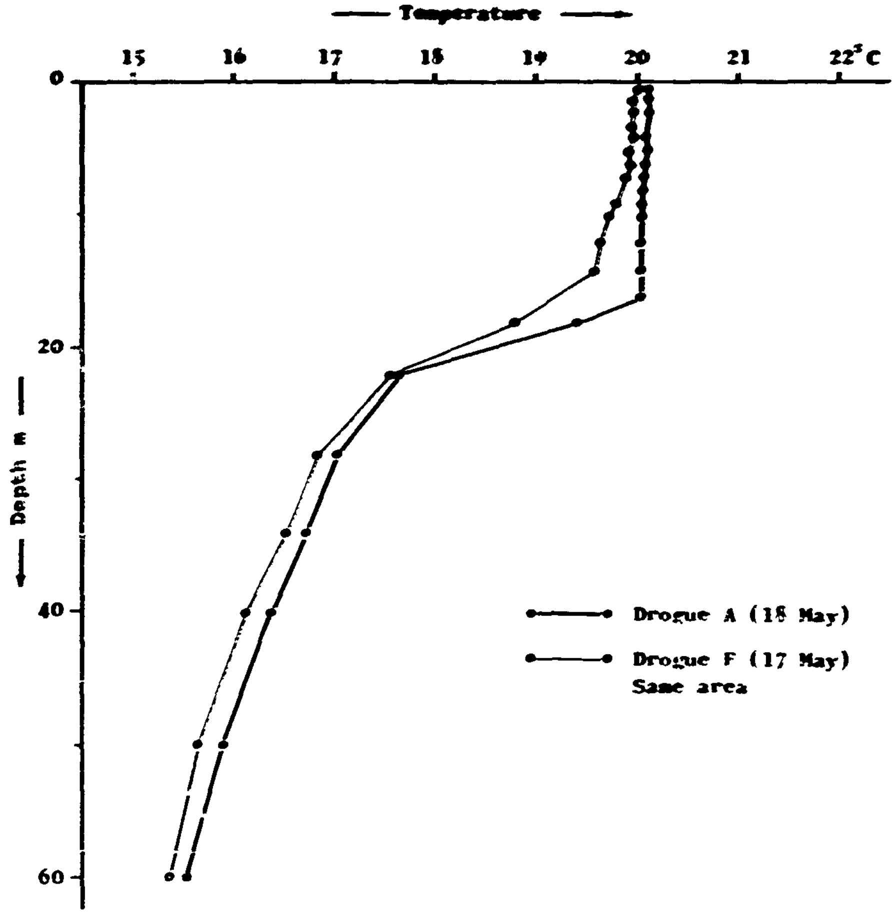


FIG. 6 TEMPERATURE PROFILES FOR DROGUE ALPHA ON 18 MAY AND DROGUE FOXTROT ON 17 MAY 1968 (approximately the same track)

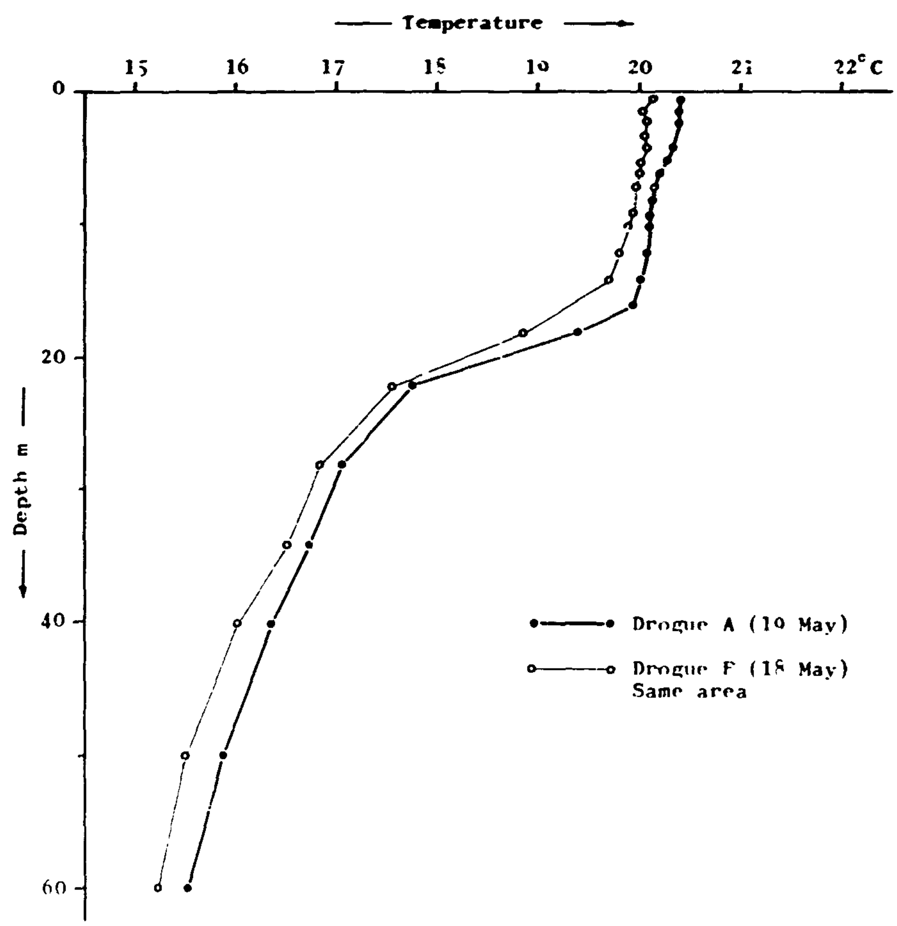


FIG. 6e TEMPERATURE PROFILES FOR DROGUE ALPHA ON 19 MAY AND DROGUE FOXTROT ON 18 MAY 1968 (approximately the same track)

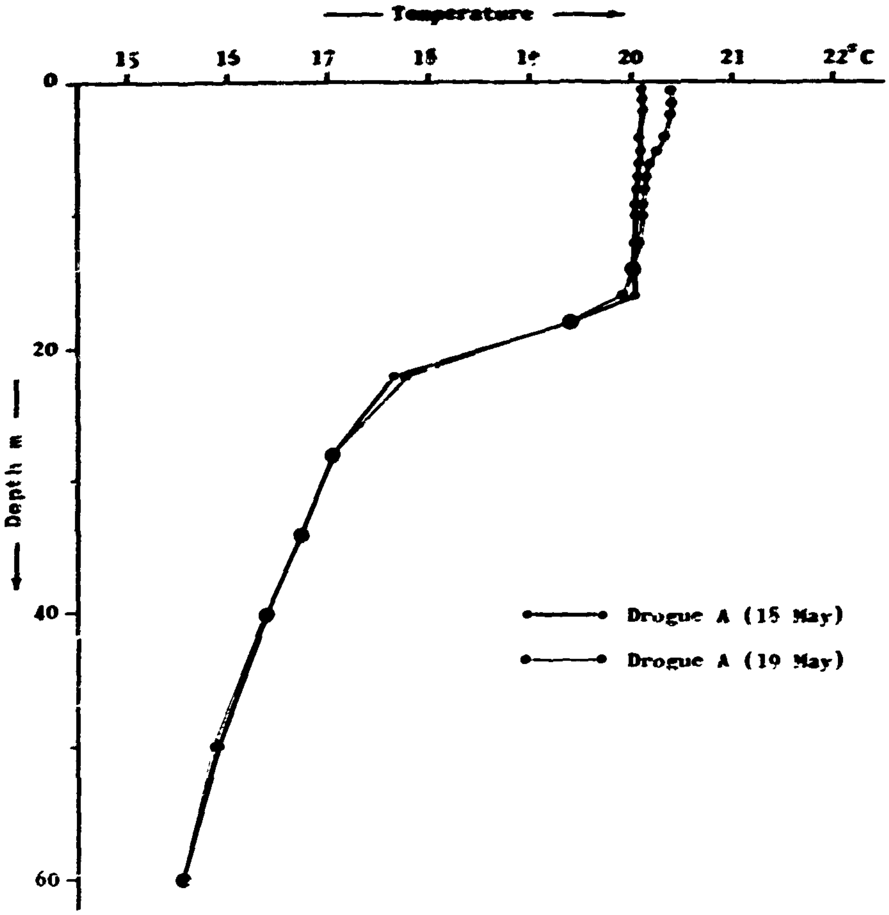


FIG. 6f TEMPERATURE PROFILES OF DROGUE ALPHA FOR 18 AND 19 MAY 1968

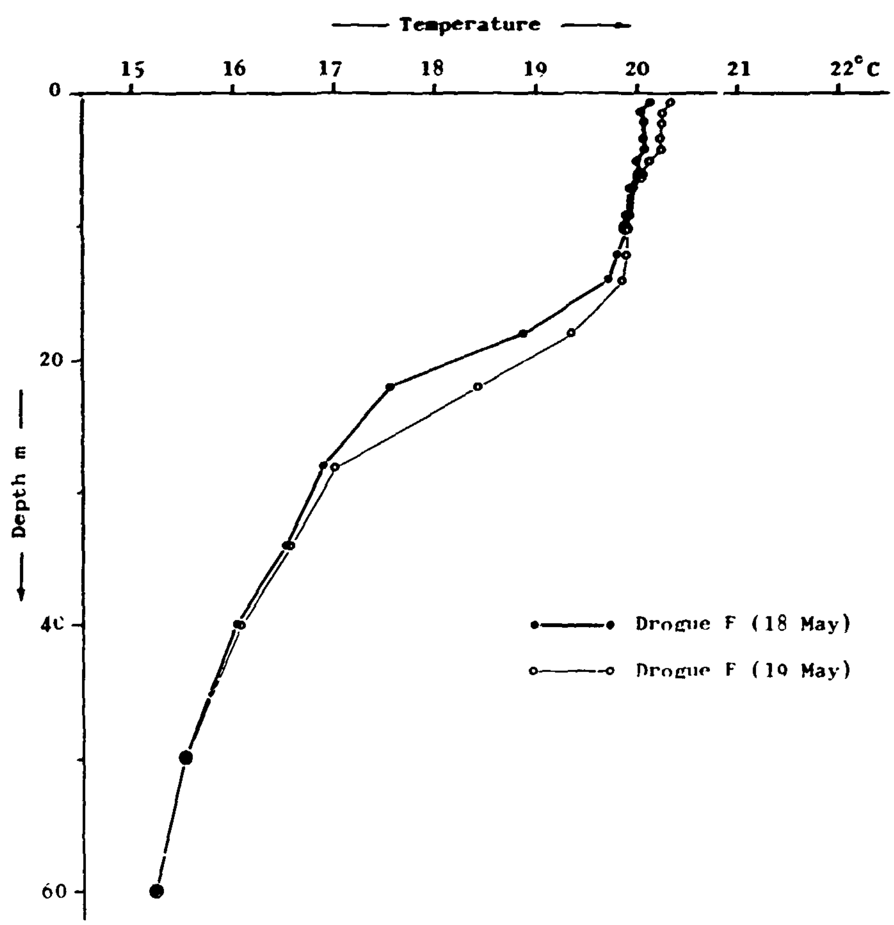


FIG. 6g TEMPERATURE PROFILES OF DROGUE FOXTROT FOR 18 AND 19 MAY 1968

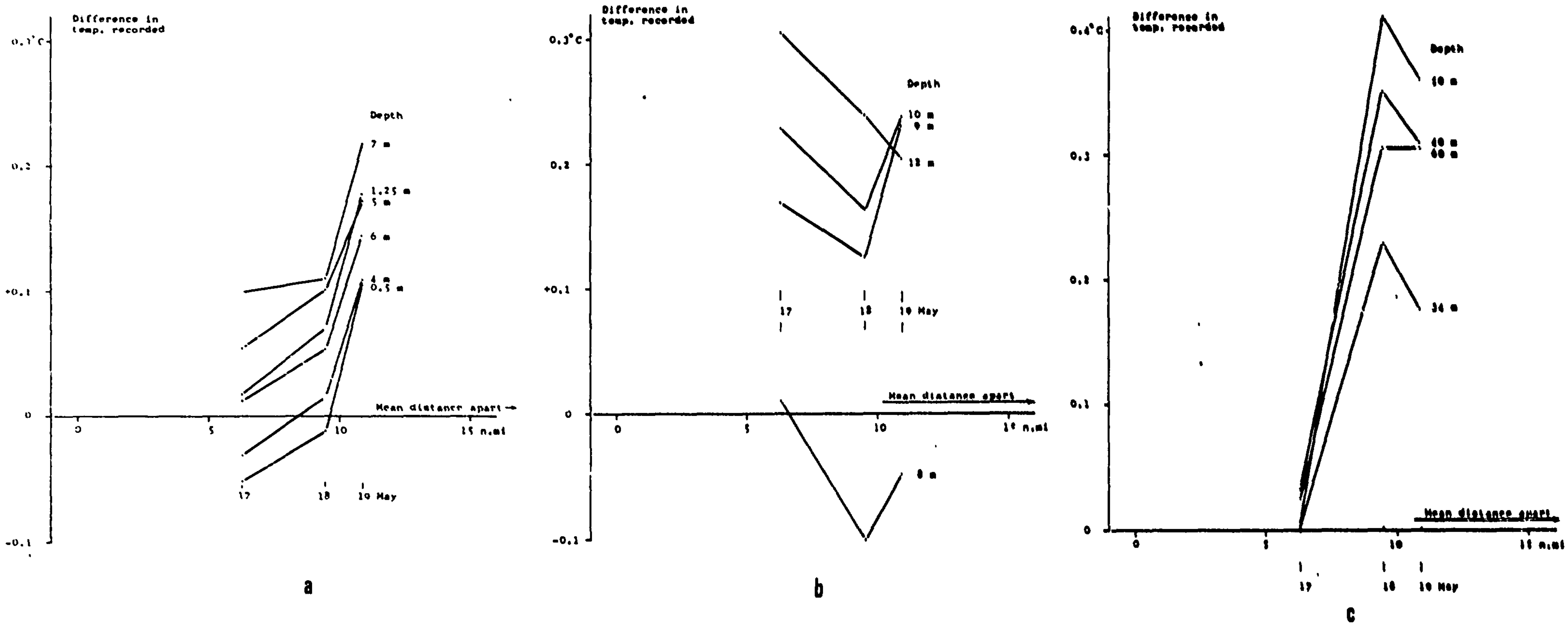


FIG. 7 DIFFERENCES IN TEMPERATURE BETWEEN DROGUE ALPHA AND DROGUE FOXTROT AS A FUNCTION OF THEIR DISTANCES APART
a. 0.5 m to 7 m b. 8 m to 12 m c. 34 m to 60 m

27.1 27.2 27.3

MILOC MED 68

DROGUE ALPHA

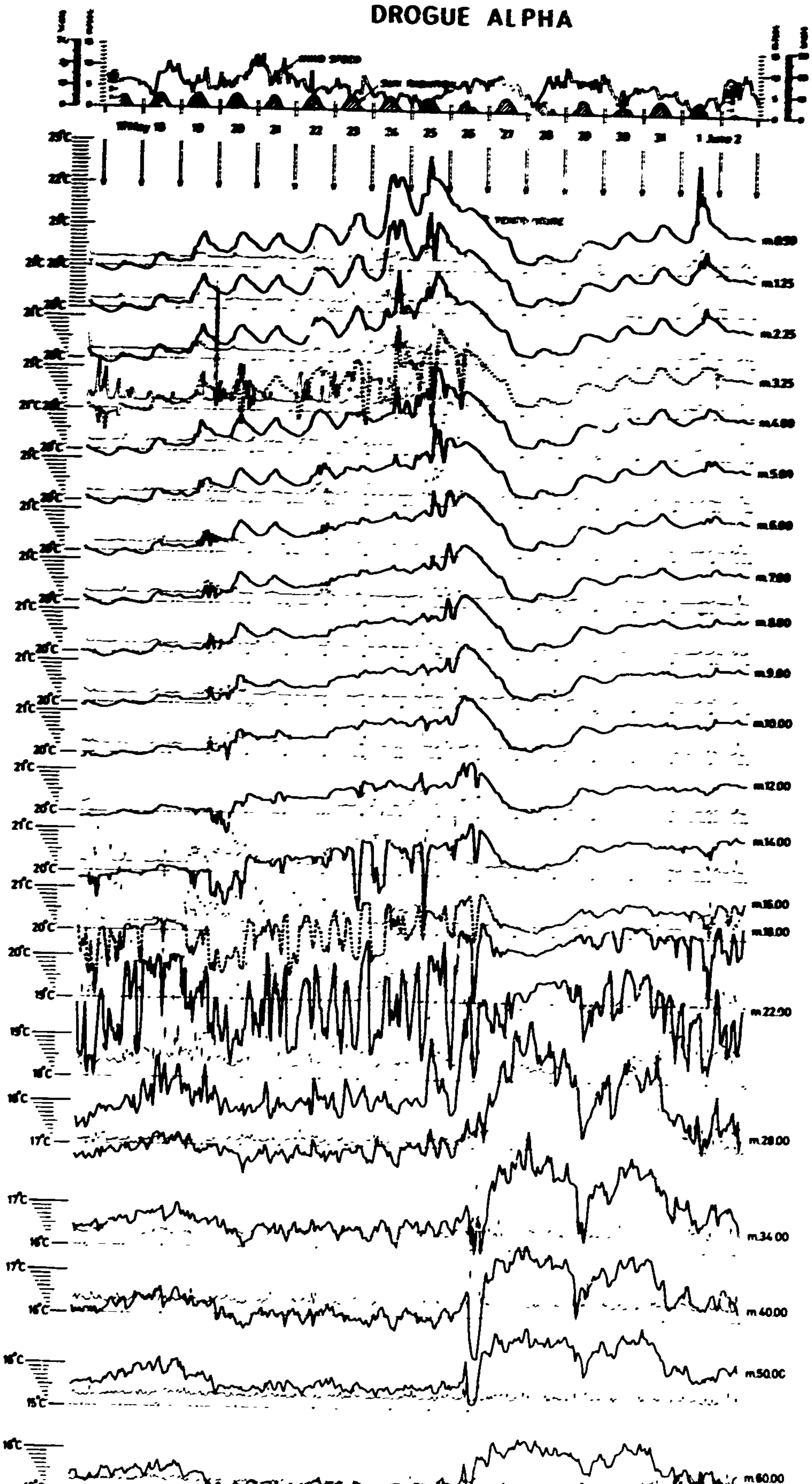


FIG. 8 HOURLY MEAN TEMPERATURES AND STANDARD DEVIATIONS COMPUTED FROM THE RECORDS OF DROGUE ALPHA (thick lines are hourly means, fine lines are standard deviations)

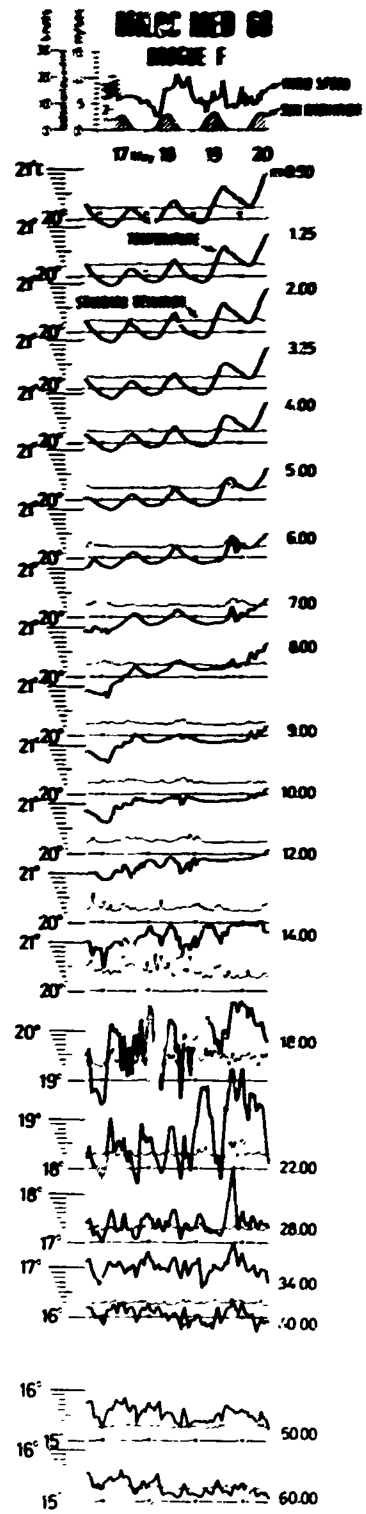


FIG. 9 HOURLY MEAN TEMPERATURES AND STANDARD DEVIATIONS COMPUTED FROM THE RECORDS OF DROGUE FOXTROT (thick lines are hourly means, fine lines are standard deviations)

MILOC MED 68
DROGUE ALPHA

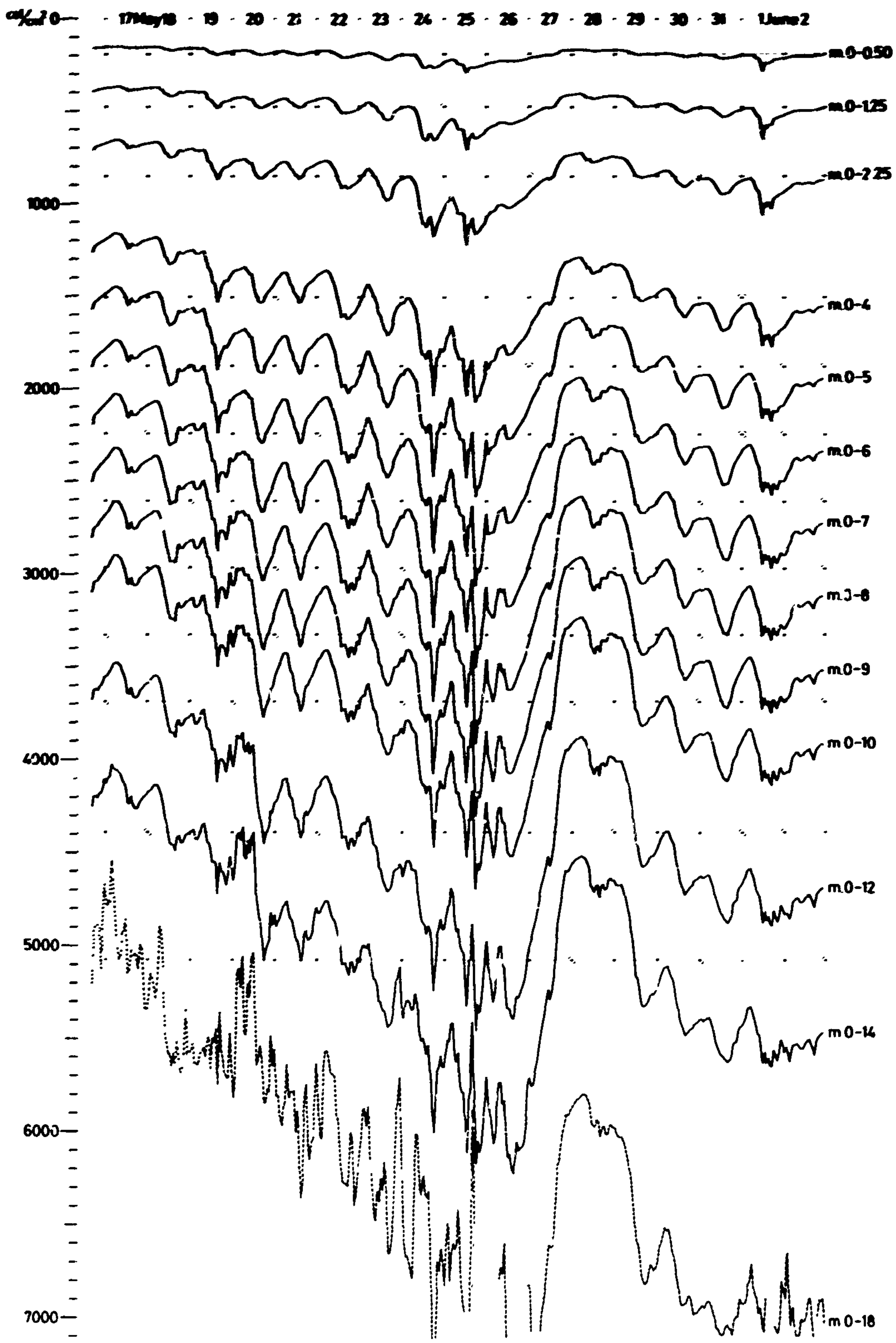


FIG. 10 HEAT CONTENT (IN EXCESS OF 17°C) IN CALORIES PER UNIT CROSS SECTION OF THE TOTAL WATER COLUMN ABOVE INDICATED DEPTHS: DROGUE ALPHA

CONCLUSIONS

So far only a very limited analysis of the data has been performed; its results may be summarized as follows:

(1) During the heating season a very pronounced daily heating cycle is observed in the upper waters of the Ionian Sea, but this variation is limited in depth to eight metres except on days with prevailing strong winds. On the other hand, calm days cause a sharp increase of the temperature very close to the surface, but there is no longer a daily heating cycle throughout the upper eight metres. There is no reason why this result should not be extended to the whole Mediterranean.

(2) Internal waves cause the temperature structure within the thermocline to change very rapidly. Although no spectral analysis has been done, the high standard deviations found for 1-hour periods suggest that the periods of these temperature variations are less than one hour.

(3) The data support the concept that horizontal temperature changes — above and below the thermocline — are not steady but occur at fairly sharp boundaries. In other words, water bodies of unknown shape and size are moving through the ocean and taking a very long time to lose their identity by mixing in the horizontal direction. It is recommended that the size of these bodies should be investigated in more detail.

Since the manuscript of this report was written there has been a further analysis of MILOC 68 data by P. Saunders of Woods Hole and F. Edwards (Royal Navy attached to SACLANTCEN). Further cruises have been made and the analysis of the results [some published (Refs. 3, 4) and some unpublished] by Woods of the UK Meteorological Office and by Briscoe and Johannessen of SACLANTCEN confirm the existence of an oceanic front or system of fronts in the area.

In particular, this frontal system appears to extend into comparatively shallow water east of Malta in summer and late spring and has been detected in deep water approximately 100 n.mi east of Malta in December. Unfortunately the drogue data reported here lack sufficient information on the lateral extent of the large variations recorded on 26-28 May to "prove" that a front was also present in the deep water in late spring — but it is an intriguing thought.

REFERENCES

1. Molcard, R. 1972. "MEDMILOC 68/Drogue Experiment Part II: A Study of a Large-Scale Diffusion", SACLANTCEN Technical Memorandum No. 182.

2. Ziegenbein, J. 1969. "The Gibraltar Buoy System", SACLANTCEN Technical Memorandum No. 144.
   [AD 856026]

3. Woods J.D. and Watson N.R. 1970. "Measurements of Thermocline Fronts from the Air", Underwater Science & Technology Journal 2, 6, 90-99.

4. Oceanography of the Strait of Sicily, Proceedings of a Conference held at SACLANTCEN, 11-13 April 1972. SACLANTCEN Conference Proceedings CP-7, 1972.