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SACLANT ASW RESEARCH CENTRE

THREE–LINE ANALYSIS OF BATHYTHERMOGRAPHS

by

J. CAPERON, B. SCHIPMOLDER and W. HARWOOD

1 MARCH 1968

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FOR THE DIRECTOR

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Deputy Director

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ABSTRACT

A method of BT analysis that fits three straight-line segments to each set of digital BT data is described. These segments are identified, in descending order, with the mixed layer, the thermocline, and the deep layer. The associated slopes, temperature ranges, and depth ranges provide statistical abstractions that can be useful in ASWEPS procedures. The results of using this method for sampling the MILOC-64 data are discussed.

INTRODUCTION

The method of analysis of digital BT data to be described is completely automatic and objective after certain initial decisions have been made. It abstracts parameters that are considered relevant to sonar range prediction and amenable to prediction in an ASWEPS programme.

The method approximates the BT data with three contiguous straight-line segments to give statistical representation of the gradients and depth ranges of the mixed layer, the thermocline, and the top section of the deep layer.

It is an attempt to explore ASWEPS techniques that lies somewhere between prediction of the total temperature profile (Ref. 1) and those techniques that rely only on layer depth and sea surface temperature (Ref. 2). Limitations in fundamental understanding of the air-sea interaction process, and limitations in the amount of current oceanographic and meteorological data available, circumscribe the accuracy of prediction of the complete profile. This should certainly be the ultimate aim of any ASWEPS programme, but such an attempt at present may well be premature. The essentially empirical approach based on sea surface temperature and layer depth seems perhaps too entirely empirical and fails to include parameters that are frequently critical to sonar range predictions (Ref. 3). It is hoped that the present method of BT-data analysis will give results useful in evaluating possibilities for a compromise ASWEPS programme and that, if this method is successful, it will be an essential part of such a programme.

1. METHOD

The method used considers representations of the points of a single BT record by three connected straight lines. A best least-squares straight line is determined for each segment. The program selects that set of lines which results in a minimum sum of squares of temperature residuals.

For a given partition the number of points associated with the first, second, and third line segment are designated $i1$, $i2$, and $i3$. The sum of squares for $i1$ is calculated by

$$\sum_{k=1}^{i1} \left[t_k - \left(a + bd_k\right)\right]^2 ,$$

where t_k and d_k are respectively the temperature and the depth of the point k, and where

$$a = \left[\sum_{k=1}^{i1} \left(t_k - bd_k\right)\right] \Big/ \, i1 ,$$

and

$$b = \left(i1 * \sum_{k=1}^{i1} d_k t_k - \sum_{k=1}^{i1} dk \sum_{k=1}^{i1} t_k\right) \Big/ \left(i1 * \sum_{k=1}^{i1} d_k^2 - \sum_{k=1}^{i1} d_k * \sum_{k=1}^{i1} d_k\right) ,$$

The terms Σd_k and Σd_k^2 are directly determined for equally-spaced depth values. The same calculations are made using similar formula for i2 and i3.

Each partition is examined, retaining the identification for only that partition which has so far resulted in a minimum sum of residuals over all three lines. Thus, at the end, the best-fit three-line segments have been found.

In practice it is found that some additional criteria improve the result by eliminating an occasionally anomalous solution that bears little relation to a correct oceanographic interpretation. The criteria are:

a. Parallel lines are excluded.

b. The depth of intersection of 1st and 2nd line segments, INT1D, must be equal to or less than the depth of intersection of the 2nd and 3rd line segments.

c. INT1D must be less than the depth of the first point of the second subset.

d. INT1D must be equal to or greater than the depth of the third from last point of the first subset.

e. The depth of intersection of the 2nd and 3rd line segment, INT2D, must be greater than the depth of the third from last point of the second subset.

f. INT2D must be equal to or less than the depth of the first point on the third line.

An optional feature of the analysis provides for separate treatment of surface transients superimposed on the mixed layer. The temperature gradient in the first 10 m and that between 10 and 25 m are calculated. If the difference between these two gradients is equal to or greater than 0.03°C per metre and this option is requested, then the points in the first 10 m are omitted from the three-line approximation. If the option is not called for, or the gradients differ by less than 0.03°C per metre, then all points are considered.

For many sets of BT data, large numbers of points are used in the third segment. In these cases it is possible to specify a minimum number of points to be included in the third segment without excluding the optimum partition. Specification of this number can be made by visual scanning of the analogue BT records. Selecting a value as large as possible will substantially reduce the computer processing time.

2. INPUT DATA

All information concerning the BT's is stored on magnetic tape (Ref. 4). For each BT there is a master block, a name block, and up to five data blocks. Each block corresponds to an 80-column punched card with one word per column and an extra word containing a sequential block number.

A punched paper tape specifies the BT's to be processed by listing the ship number, the starting BT number, and the ending BT number. The minimum number of points to be included in the third line segment, and whether or not the surface transient option is to be used, are also specified.

3. OUTPUT

An output magnetic tape contains

a. The number of points in each of the three subsets of the partition.

b. The slopes of the three lines and the temperature and depth coordinates of each of the end points of the three segments.

c. The sum, sum of squares, and sum of cross products for temperature and depth.

The original BT data is included on this output tape.

This output tape is a source tape for a program that generates a plot (e.g. Fig. 1) of the three lines and the original BT data. It is the source data for the output listing of the three-line data given in Table 1. Finally it forms the source data for statistical studies on the goodness-of-fit of the line segments and for general oceanographic interpretation of the BT data.

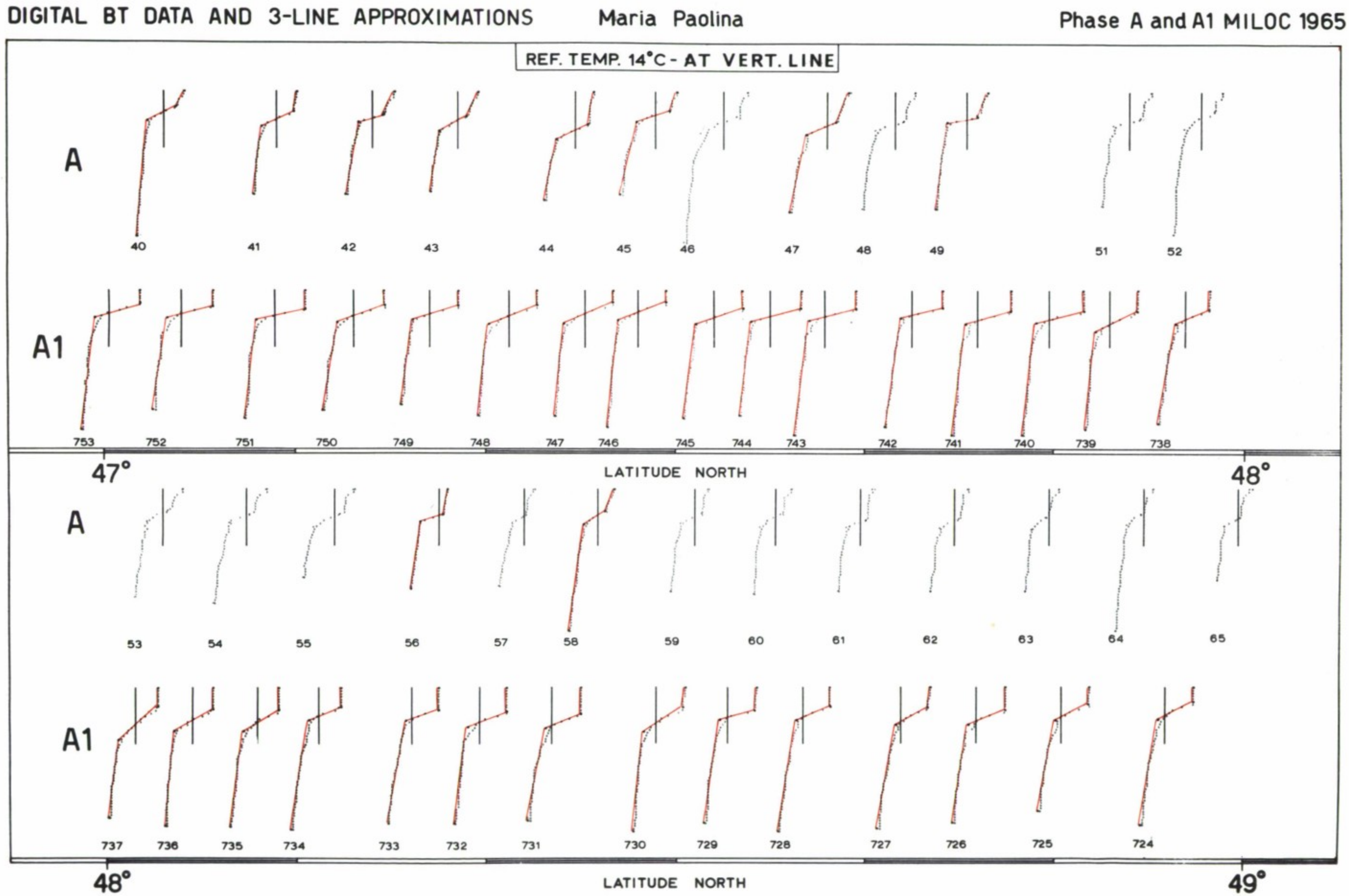

FIG. 1 EXAMPLE OF OUTPUT PLOT SHOWING ORIGINAL BT DATA AND THE THREE-LINE APPROXIMATIONS

TABLE 1

EXAMPLE OF PRINTED OUTPUT (see opposite)

SHIP	=	Ship's identification number
DA MO YR	=	Date, month, year
BT	=	BT number
TIME		
VAR	=	Standard error of estimate of first line segment
LD	=	Layer depth (metres)
TD	=	Depth of bottom of thermocline (metres)
TRAN	=	Temperature gradient in first 10 m
SL1	=	Temperature gradient of first line segment
SL2	=	Temperature gradient of second line segment
SL3	=	Temperature gradient of third line segment

SHIP	DA	MO	YR	BT	TIME	VAR	LD	TD	TRAN	SL1	SL2	SL3
6387	28	06	65	0009	0001	0.512	036	059	.000	-.004	-.190	-.006
6387	28	06	65	0010	0030	0.000	032	054	.000	.000	-.184	-.009
6387	28	06	65	0011	0100	0.305	042	082	.000	-.007	-.108	-.005
6387	28	06	65	0012	0130	0.305	041	083	.000	-.013	-.089	-.007
6387	28	06	65	0013	0200	0.510	042	071	-.000	-.012	-.115	-.006
6387	28	06	65	0014	0300	-0.000	034	062	.000	-.000	-.124	-.005
6387	28	06	65	0015	0330	0.067	047	072	-.000	-.001	-.140	-.004
6387	28	06	65	0016	0400	0.000	031	064	-.000	.000	-.102	-.005
6387	28	06	65	0017	0500	0.000	042	071	-.000	.000	-.106	-.007
6387	28	06	65	0018	0530	0.000	038	063	-.000	.000	-.124	-.006
6387	28	06	65	0019	0600	-0.000	026	058	.000	-.000	-.094	-.007
6387	28	06	65	0020	0700	0.031	033	053	-.000	.004	-.152	-.006
6387	28	06	65	0021	0730	0.039	028	057	-.000	-.002	-.112	-.004
6387	28	06	65	0022	0800	0.026	028	057	.000	.005	-.109	-.005
6387	28	06	65	0023	0900	0.000	032	053	.000	.000	-.154	-.005
6387	28	06	65	0024	0930	0.000	034	053	.000	.000	-.180	-.003
6387	28	06	65	0025	1000	0.604	037	052	-.000	-.008	-.210	-.004
6387	28	06	65	0026	1100	0.048	038	068	-.000	-.002	-.111	-.005
6387	28	06	65	0027	1130	0.053	033	062	-.010	-.007	-.116	-.005
6387	28	06	65	0028	1200	0.305	043	062	-.000	-.007	-.173	-.005
6387	28	06	65	0029	1300	0.165	033	063	-.010	-.011	-.102	-.005
6387	28	06	65	0030	1330	0.122	045	073	.000	-.007	-.108	-.005
6387	28	06	65	0031	1400	0.968	047	067	-.000	-.013	-.138	-.007
6387	28	06	65	0032	1500	0.178	037	072	-.010	-.005	-.098	-.006
6387	28	06	65	0033	1530	0.044	031	052	-.010	-.010	-.138	-.008
6387	28	06	65	0034	1600	0.026	027	062	-.010	-.005	-.087	-.008
6387	28	06	65	0035	1700	0.094	038	057	.000	-.007	-.162	-.007
6387	28	06	65	0036	1730	0.103	034	053	-.020	-.014	-.152	-.007
6387	28	06	65	0037	1800	0.450	037	067	-.010	-.035	-.082	-.006
6387	28	06	65	0038	1900	0.148	040	067	-.010	-.022	-.092	-.006
6387	28	06	65	0039	1930	0.224	038	062	-.020	-.028	-.094	-.005
6387	28	06	65	0040	2000	0.128	027	052	-.010	-.028	-.098	-.005
6387	28	06	65	0041	2100	0.053	035	061	.000	-.007	-.104	-.006
6387	28	06	65	0042	2130	0.459	041	053	.000	-.025	-.180	-.008
6387	28	06	65	0043	2200	0.325	042	068	-.010	-.024	-.093	-.007
6387	28	06	65	0044	2300	1.100	057	083	-.010	-.008	-.110	-.010
6387	28	06	65	0045	2330	0.267	033	052	-.030	-.020	-.152	-.011
6387	28	06	65	0046	2400	0.768	043	072	-.040	-.022	-.110	-.008
6387	29	06	65	0047	0100	0.610	052	074	-.050	-.022	-.118	-.011
6387	29	06	65	0048	0130	1.857	052	067	-.010	-.020	-.160	-.008

4. TEST WITH MILOC 64 DATA

A test of the program was made on twenty randomly-selected BT's from the MILOC 64 Phase A data. The mean standard error for these BT's is given in Table 2. The depth of intersection of the first and second line segment can be identified with "layer depth" and is the point of separation between the first (mixed) layer and the thermocline.

Table 2 contains a comparison between the layer depth, so defined, and layer depths computed by an earlier program used to determine layer depth based on a consideration of curvature of the BT trace. The difference exceeds 2 metres in four cases. Results more consistent with a subjective determination are provided by the present method in three of these cases and by the older method in the fourth case. It is clear that whenever the concept of layer depth has real meaning the present method will nearly always give a good result unaffected by small thermocline superimposed on the mixed layer.

The mean standard error of estimate for the twenty cases is 0.145 °C. The success of the program for the MILOC 64 data is surprisingly good. These BT records were taken in September — during the cooling season. The mixed layer was uniformly evident and well represented by a straight line. It could be expected that this condition would continue during the remainder of autumn and winter. Experience with the MILOC 65 data from June shows equally good fits in only 60 to 70% of the cases. The remaining cases show a strong transient in the first 5 to 15 metres due to heating. The analysis is of less value in these cases and, indeed, the concept of "layer depth" itself is of questionable importance here.

A copy of the computer program and data handling procedures are available from **SACLANTCEN**.

TABLE 2

BT No.	Ship	Layer Depth (metres)			Standard Error for three lines (°C)
		Old Method	Present Method	Absolute Diff.	
57	JOÃO DE LISBOA (06353)	26	27	1	0.24
121		48	49	1	0.11
169		43	41	2	0.17
164		48	49	1	0.066
227		43	42	1	0.24
139	DALRYMPLE (06354)	50	49	1	0.13
152		45	45	0	0.089
271		48	24	4	0.15
587		57	57	0	0.12
612		51	49	2	0.16
14	SVERDRUP (06356)	35	33	2	0.18
22		39	41	2	0.130
32		54	29	25	0.080
41		31	29	2	0.14
48		53	44	9	0.14
8	MARIA PAOLINA (06357)	33	30	3	0.28
130		54	55	1	0.12
147		54	54	0	0.099
175		36	34	2	0.14
219		33	34	1	0.12

REFERENCES

1. U.S. Naval Weather Service Computer Products Manual. NAVAIR 50-IG-522.

2. ASWEPS Concept, ASWEPS Manual Series, Vol. 1, SP 105, USN Hydrographic Office.

3. National Oceanographic Data Center, Manual Series Pub. M-3 (Provisional). Manual for processing Bathythermograph Data. Part 1, "Instructions for Manually Digitizing Bathythermograph Data".

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