Miscellaneous Publication N.Z. Oceanographic Institute 73.

ROUTINE PHYSICAL OCEANOGRAPHIC DATA REDUCTION USING A PROGRAMMABLE DESK CALCULATOR

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February 1976

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ABSTRACT

Simple programmes developed for the correction of reversing thermometer readings, the determination of depth of reversal and the conversion of conductivity ratios to salinity are described. These programmes are suitable for small programmable desk calculators, such as the Canola 164 P. A method for producing Canola punch cards from standard 80-column I.B.M. cards is also described.

INTRODUCTION

The routine and repetitive tasks of correcting reversing thermometer readings and the determining of depths of reversal and salinity from conductivity, can be done quickly and accurately using a small programmable desk calculator. The programmes described here have been designed specifically for use with a Canola 164 P machine with its limit of 64 programme steps but could be used equally well with any similar calculator. Some familiarity with the operation of the Canola 164 P as described in the Instruction Manual (Canon Inc. 1970) is assumed.

The programmes for reversing thermometer corrections and depths of reversal follow the methods used in constructing the Culbertson oceanographic slide rule (Culbertson 1955) and thus both methods are compatible. The salinity from conductivity programme is designed to reproduce the values given in the International Oceanographic Tables (NIO and UNESCO 1966) and hence be interchangeable with them. Both the depth of reversal and the salinity from conductivity programmes contain approximation formulae, as outlined below, and consequently are accurate only over specific ranges of the variables concerned. These ranges are, however, those normally encountered in oceanic waters, so the programmes are sufficiently accurate for practical use.

A method developed for producing Canola 164 P punch cards from standard 80-column I.B.M. punch cards is described in Appendix I. The oceanographic programmes are listed in Appendix II.

REVERSING THERMOMETER CORRECTIONS

Reversing thermometer readings are first corrected for any index error (I) resulting from incorrect etching of the thermometer scale or from variations in the diameter of the capillary. This correcting, along with the other individual thermometer constants V_0, K and Q are shown on the thermometer certificate or listed in the current tabulation of thermometer constants.

A second correction for thermal expansion subsequent to reversal (C for protected, C_u for unprotected thermometers) must be applied to reversing thermometer readings. These corrections as given by Sverdrup (1947) are

$$C = \frac{(V_o + T')\ (T' - t)}{K - (V_o + T') - (T' - t)}$$

$$C_u = \frac{(V_o + T')\ (T_W - t)}{K - (T_W - t)}$$

where

V_o = Volume of mercury (in °C) below 0°C when thermometer reversed

K = Reciprocal coefficient of thermal expansion of the thermometer glass

T' = Main thermometer reading [after index correction has been applied]

t = Auxilary thermometer reading [after index correction has been applied]

T_W = Water temperature at depth of reversal (i.e. corrected protected thermometer reading).

The Canola 164 P programmes for both protected and unprotected thermometer compute C or C_u then display the corrected thermometer reading.

Procedure

1. Enter protected or unprotected thermometer programme. Set Dial (2).
2. Put V_o in M1 (memory 1) and K in M2 (memory 2). These values remain in memory at the end of the calculation.
3. Apply index correction I to raw data.
4. Enter T' then t.
5. Enter T_W in case of unprotected thermometer.
6. Read off T_W or T_u.

DEPTH OF REVERSAL

The depth of reversal, D, as determined from the corrected thermometer readings was given by Wust (1933).

$$D = \frac{(T_u - T_W)}{\rho_m\ Q}$$

where

T_u = Corrected unprotected thermometer reading.

T_W = Corrected protected thermometer reading.

ρ_m = Mean density *in situ* of water column above the level of reversal.

Q = Pressure coefficient of individual unprotected thermometer.

The mean depth integrated density ρ_m varies with depth and conventionally this variation is allowed for by taking the average variation of ρ_m over several North Atlantic stations as a standard for use with all other station data (*see* Culbertson 1955).

Using the North Atlantic data we can write

$$D = D^1 + \Delta D \qquad (1)$$

where

D^1 = Depth of reversal calculated using a constant value of ρ_m equal to ρ_m at 1000 m

i.e.

$$D^1 = \frac{(T_u - T_W)}{1.0294\ Q} \qquad (2)$$

and

ΔD = Correction due to changes in ρ_m with depth from its value at 1000 m.

The correction ΔD is small and is applied from tabulated values by Culbertson (1955). For programme use this correction has been approximated by the quadratic expression

$$\Delta D = 2.6\ (1 - D^1/1000)\ D^1/1000 \qquad (3)$$

In the Canola 164 P programme the depth of reversal is calculated from equations 1, 2 and 3. In Table 1 the values of ΔD found from the tabulation

TABLE 1. Comparison of depth correction, ΔD, from tabulation (Culbertson 1955) and quadratic approximation (equation 3).

D	ΔD Culbertson 1955	ΔD Equation 3	Difference
200	0.50	0.42	0.08
400	0.70	0.62	0.08
600	0.70	0.62	0.08
800	0.70	0.42	0.08
1000	0	0	0
1500	-2.00	-1.95	-0.05
2000	-5.20	-5.20	0
2500	-9.70	-9.75	+0.05
3000	-15.20	-15.60	+0.40
3500	-21.80	-22.75	+0.95
4000	-29.80	-31.20	+1.40

TABLE 2. Some test data for use with Canola 164P programmes.
$V_0 = 100$, $K = 6100$ $Q = 0.01$

Programme	Data				Result
Protected thermometer correction	$T' = 10$		$t = 11$		$T_w = 9.98$
	$T' = 10$		$t = 9$		$T_w = 10.02$
Unprotected thermometer correction	$T' = 10$	$t = 11$	$T_w = 10$		$T_u = 9.98$
	$T' = 10$	$t = 9$	$T_w = 9$		$T_u = 10.00$
Depth of reversal	$T_u = 20$		$T_w = 15$		$D = 486.3695$
Salinity from conductivity	$R = 0.98$				$S = 34.2173$
	$R = 1.00$				$S = 35.0001$
	$R = 1.02$				$S = 35.7856$

(Culbertson 1955) and the quadratic approximation (equation 3) are compared. All depths are in metres. From this Table it can be seen that the depth of reversal computed by the programme is correct to ±0.5 metre in the upper 3000 m. In the upper 2500 m thermometric depths are correct to less than 0.1 metres. For depths greater than 3000 m an additional correction as given by the differences column in Table 1 is necessary.

Procedure

1. Enter programme. Set Dial 4.
2. Put Q in M1. This value remains in memory at the end of the calculation.
3. Enter T_u then T_w.
4. Read off depth in metres.

SALINITY FROM CONDUCTIVITY

The salinity, S, is determined from the ratio of the electrical conductivity of the sample to that of a standard water whose salinity is 35.0‰. The conductivity ratios are found using an inductively coupled salinometer and are then converted to salinity values at the standard temperature (15°C) by calculation using a fifth order polynominal or from tabulated values as in the International Oceanographic Tables (NIO and UNESCO 1966). For conditions normally encountered a suitable quadratic approximation was derived for equation 4.

$$S = 3.4283 R^2 + 32.3511 R - 0.7793 \quad (4)$$

This equation gives salinity (at 15°C) with an error of less than 0.001‰ over the range 29.2‰ to 41.7‰, the range covered by Table 1A in the International Oceanographic Tables.

Procedure

1. Enter programme. Set dial (4).
2. Enter R.
3. Read off S in ‰.

GENERAL NOTES ON USING CANOLA 164P PROGRAMMES

1. Clear all memories not containing required constants before first run. Subsequently memories are cleared by the programme.
2. If programme stops part way through a calculation constants may be lost from memories. Check memories before re-running programme.
3. Some test data with typical values of thermometer constants is given in Table 2.

REFERENCES

CANON INC. 1970: "Canola 164P Instruction Manual".

CULBERTSON, M.F. 1955: An oceanographic slide rule for computing temperature, depth and salinity. *Trans. Am. geophys. Un. 36(3)* : 473-80.

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APPENDIX I

Card Punching for Canola 164 P Programmable Desk Calculators

Programme cards for the Canola 164 P can be punched on an I.B.M. 029 card punch. The major advantages of speed and ease of duplication are achieved.

The perforated Canon Program Card used with the Canola 164 P is one inch narrower than the standard IBM card and when punched uses only rows, Y, O, 1, 2, 3, 4, 5, with double spacing, i.e., uses only evenly numbered columns. Using the characters, -, 0, 1, 2, 3, 4, 5, and the multiple punch key all required combinations can be punched as in the Table below (which follows that in the Canola Instruction Manual, p.54).

I.B.M. Card Punch		-	0	-0	1	-1	01	-01	2	-2
		=	-=	x	÷	sq.rt				
3		J								
4		M 1	M 2	M 3	SM 4					
4 3		-M 1	-M 2	-M 3						
5		RM 1	RM 2	RM 3	RM 4					
5 3	C I	CM 1	CM 2	CM 3						
5 4	.	RV	→							
5 43	0	1	2	3	4	5	6	7	8	9

Note that using MULT. PUNCH key automatically gives numeric or upper register symbols, consequently the only keys used are MULT. PUNCH and SPACE (left hand) and numeric keys plus - key all in the right corner of the keyboard.

If master cards of each programme are made then duplicates can be run off with ease. Before use these duplicates are guillotined along the middle of the row of 6's, to fit the Canola 164 P. Because of the light system used in the Canola card reader, blue cards are required or other cards can be used provided the backs are blackened (e.g., with a felt pen).

APPENDIX II

Canola 164 P Programme Listings

1. Protected thermometer correction

Step	Oper-ation	Comment	Step	Oper-ation	Comment	Step	Oper-ation	Comment
1	J	Read T'	10	=		19	C I	
2	M 3		11	÷		20	RM 3	
3	M 1		12	RM 1		21	- =	
4	J	Read t	13	RV		22	M 1	
5	- =		14	- =		23	C I	
6	SM 4		15	X		24	RM 4	
7	RM 2		16	RM 4		25	M 3	
8	- =		17	=	C	26	RM 3	T_w
9	RM 1		18	SM 4		27	CM 3	

2. Unprotected thermometer correction

Step	Oper-ation	Comment	Step	Oper-ation	Comment	Step	Oper-ation	Comment
1	J	Read T'	11	RM 2		21	SM 4	
2	M 3		12	RM 4		22	C I	
3	M 1		13	- =		23	RM 3	
4	C I		14	÷		24	- =	
5	J	Read t	15	RM 1		25	M 1	
6	- =		16	RV		26	C I	
7	J	Read T_w	17	=		27	RM 4	C_u
8	=		18	x		28	M 3	
9	SM 4		19	RM 4		29	RM 3	T_u
10	C I		20	=	C_u	30	CM 3	

3. Depth of Reversal

Step	Operation	Comment	Step	Operation	Comment	Step	Operation	Comment
1	J	Read T_u	13	÷		25	- =	
2	=		14	RM 1		26	x	
3	J	Read T_w	15	=	D^1	27	2	
4	- =		16	M 2		28	·	
5	÷		17	÷		29	6	
6	1		18	1		30	- =	
7	·		19	0		31	x	
8	0		20	0		32	RM 4	
9	2		21	0		33	=	ΔD
10	9		22	=		34	M 2	
11	4		23	SM 4		35	RM 2	D
12	=		24	1		36	CM 2	

4. Salinity from Conductivity

Step	Operation	Comment	Step	Operation	Comment	Step	Operation	Comment
1	J	Read R	13	M 2		25	·	
2	M 1		14	RM 1		26	7	
3	x		15	x		27	7	
4	=		16	3		28	9	
5	x		17	2		29	3	
6	3		18	·		30	-M 2	
7	·		19	3		31	RM 2	S
8	4		20	5		32	CM 1	
9	2		21	1		33	CM 2	
10	8		22	1		34	J	
11	3		23	=				
12	=		24	M 2				

(Received for Publication – 12 December 1974)