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Application of Acoustic-Doppler Current Profiler and Expendable Bathythermograph measurements to the study of the velocity structure and transport of the Gulf Stream

by

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Contents

Figures

Tables

ABSTRACT

We have addressed the degree to which Acoustic-Doppler Current Profiler (ADCP) and expendable bathythermograph (XBT) data can provide quantitative measurements of the velocity structure and transport of the Gulf Stream. An algorithm has been used to generate salinity from temperature and depth using an historical Temperature/Salinity relation for the NW Atlantic. Results have been simulated using CTD data and comparing real and pseudo salinity files. Errors are typically less than 2 dynamic cm for the upper 800 m out of a total signal of 80 cm (across the Gulf Stream). When combined with ADCP data for a near-surface reference velocity, transport errors in isopycnal layers are less than about 1 Sv ($10^6 m^3/s$), as is the difference in total transport for the upper 800 m between real and pseudo data. The method is capable of measuring the real variability of the Gulf Stream, and when combined with altimeter data, can provide estimates of the geoid slope with oceanic errors of a few parts in 10^8 over horizontal scales of 500 km.

1 INTRODUCTION

Soon after it leaves Cape Hatteras, the Gulf Stream transport increases to values of 150 Sv (1 Sv = $10^6 m^3/s$), over five times that of its parent, the Florida Current. Little is known about the structure and variability of the recirculation regime responsible for the transport increase. Altimeter measurements at the surface suggest that the spectrum of variability is broad: ranging from month-scale changes, associated with meandering, as well as seasonal and annual shifts in position and strength of the Gulf Stream. In order to be able to extend surface measurements to depth, in-situ hydrographic studies using shipboard measurements can use the geostrophic approximation and infer transport relative to some reference level of known motion. Historical measurements (see Worthington, 1976) have used deep current measurements from floats or current meters. Recently Halkin and Rossby (1985) have reported on Pegasus velocity profiles in which Gulf Stream transects have been made with an acoustically tracked device. While adequate for Gulf Stream monitoring, the technique is very labor-intensive, requiring a bottom transponder array, several days of ship time for a single crossing, and repeated sections for time series study. An alternative method using CTD stations and Acoustic Doppler Current Profilers (ADCP) reported by Joyce, Wunsch, and Pierce, 1986 (JWP) and Pierce and Joyce, 1988 (PJ) also requires the use of a dedicated research vessel, but not as much ship time nor any transponder network. In this report, we will investigate a variant of the ADCP/CTD/inverse method used by JWP and PJ, which would use expendable bathythermographs (XBT's) and an ADCP from a moving vessel. While the method suffers from making measurements only in the upper ocean, it has the advantage that the vessel does not need to stop, and offers the further possibility that these measurements can be made from ships-of-opportunity in the future.

In this report, we will use data collected from sections across the Gulf Stream made in the Warm Core Rings experiment: the same data as that used in JWP and PJ. The ADCP data were used to provide an initial guess at the reference level velocity, and were combined with deep CTD casts to estimate the total velocity field on two intersecting transects of the Gulf Stream (Fig 1).

Inverse methods (eg. Wunsch, 1978) were invoked to refine the reference velocities so as to conserve total mass (to 0.1 Sv) as well as transports in individual layers. Readers are referred to JWP and PJ for a discussion of the methods and results. The ADCP data alone suffer from random and systematic errors, the latter of some concern as they create large initial imbalances in transport comparing the two sections in Fig. 1. The cause of these errors comes from gyro/transducer misalignment and deviations from the ideal beam geometry (see Joyce, 1988). Despite these shortcomings of the ADCP measurements, the combined data are superior to the hydrographic measurements alone because the velocity of the Gulf Stream is large and extends all the way to the ocean bottom (i.e., there is no level of no motion). The station pattern and near surface (60-100m) currents during a four day survey in August 1982 in Fig 1 has a pie-shaped geometry with the open side along the 200 m isobath. A similar pattern to that in Fig 1 (from PJ) was observed in June and reported by JWP. Arguments were made that the open boundary along the continental shelf contributed negligible volume transport into the region and could be ignored in comparison to the large transports across the two Gulf Stream sections.

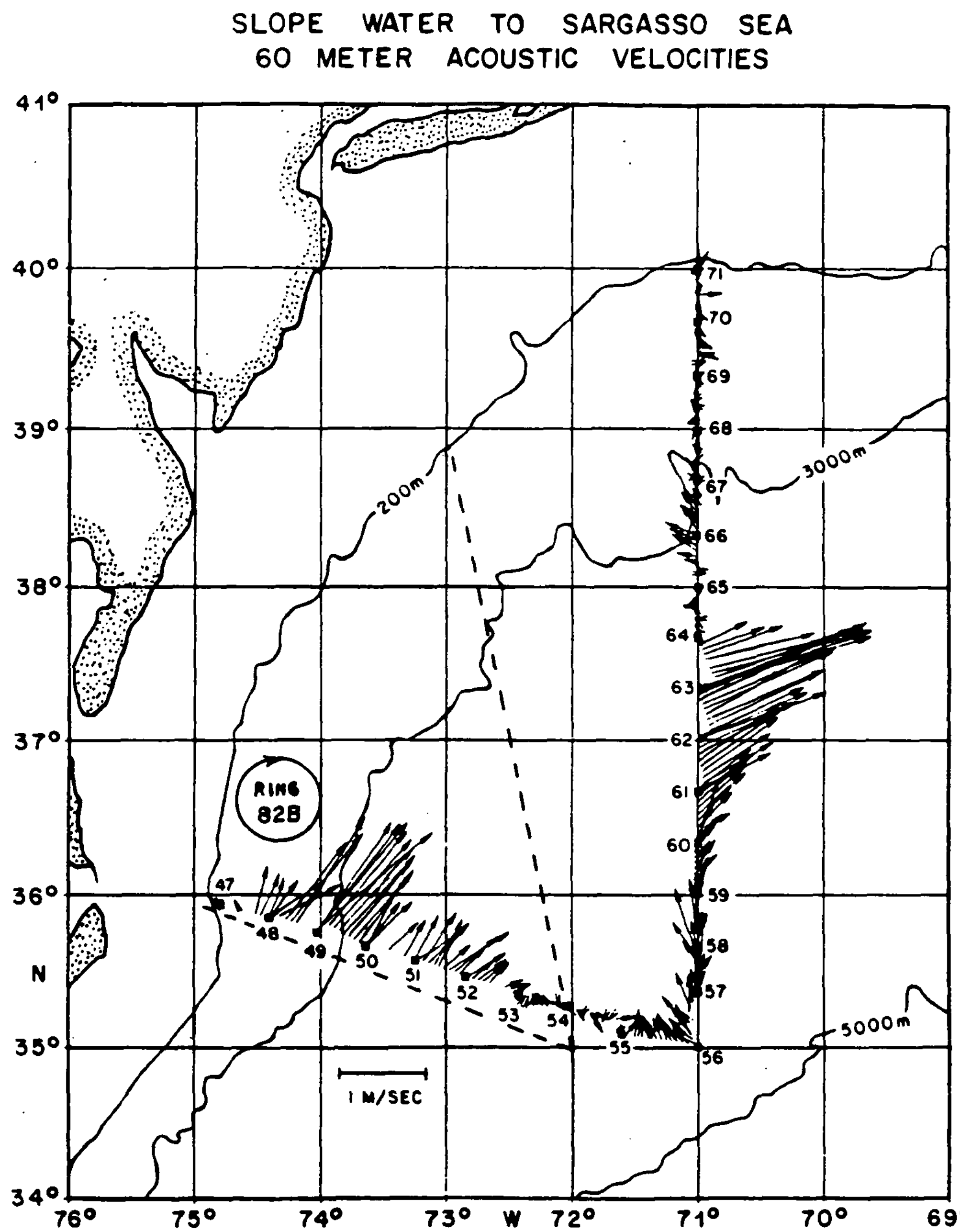

Figure 1: Station locations for CTD/O_2 casts and ADCP measurements at a depth of 60 m during EN88 (from PJ) during August 1982. Also shown (dashed lines) is the track pattern from EN86 used in JWP.

We have used the "corrected" ADCP data from the inverse calculation for this study. In order to simulate XBT's, the salinity measurements were deleted from the CTD files and an algorithm was used to regenerate an estimated salinity from temperature and depth alone. In the next section, we will describe the results from the pseudo-salinity calculation (the algorithm is given in the appendix) in terms of tabulated errors in dynamic height as a function of depth and hydrographic regime. This is followed by a comparison of velocity and transport calculations in the upper 800 m as well as in selected potential density layers. A final section summarizes the results and considers the possibility of application to future Gulf Stream investigations.

2 SALINITY ESTIMATION AND DYNAMIC HEIGHT ERRORS

The CTD data from two cruises aboard the R/V ENDEAVOR (86, 88) were truncated at 800 m. In the pseudo salinity files, the original salinity was replaced by one calculated from temperature and depth (or pressure) alone. Results are summarized in tables 1-3 for the Sargasso Sea, Slope Water, and Gulf Stream, respectively. The procedure used in generating the pseudo salinities was as follows:

- Starting at the bottom of the cast (800m) use temperature and depth and the T/S relation for the NW Atlantic Central Water (Armi and Bray, 1982) to estimate a salinity.
- When a depth of 200 m is reached, take the salinity to be constant to the surface unless a specified temperature inversion (typically 0.5° C) is encountered.
- If an inversion is encountered, use temperature and depth and linearly interpolate the last salinity towards a T/S value of 8° C/32.5 psu, which is characteristic of the shelf water.

The method was tested on the EN86 data and applied to both data sets comparing the measured salinities and dynamic heights. The latter are of particular interest since we desire to use the pseudo salinity data for dynamic calculations for the geostrophic flow relative to the ADCP data. Because of the change in the algorithm at 200 m depth, we have tabulated dynamic heights from the pseudo and real data for 0-200 m, 200-800m and 0-800m depth.

Table 1: Pseudo and real dynamic heights (dyn m) for the Sargasso Sea stations.

Endeavor 86

Sta #	0-200 db			200-800 db			0-800 db		
	pseudo	real	diff.	pseudo	read	diff.	pseudo	real	diff.
47	.4935	.4971	-.0036	.9344	.9285	+.0059	1.4279	1.4256	+.0023
48	.4718	.4598	+.0120	.9662	.9600	+.0062	1.4380	1.4198	+.0182
49	.4324	.4349	-.0025	1.0036	.9981	+.0055	1.4360	1.4330	+.0030

Endeavor 88

52	.4656	.4761	-.0105	.9439	.9449	-.0010	1.4095	1.4210	-.0115
53	.4766	.4880	-.0114	.9778	.9782	-.0004	1.4544	1.4662	-.0118
54	.4882	.4967	-.0085	.9772	.9784	-.0012	1.4654	1.4751	-.0097
55	.4684	.4754	-.0070	.9570	.9588	-.0018	1.4254	1.4342	-.0088
56	.5041	.5155	-.0114	.9846	.9840	+.0006	1.4887	1.4995	-.0108
57	.5144	.5299	-.0155	.9888	.9894	-.0006	1.5032	1.5193	-.0161
58	.5185	.5277	-.0092	.9917	.9911	+.0006	1.5102	1.5188	-.0086
59	.5136	.5204	-.0068	.9945	.9925	+.0020	1.5081	1.5129	-.0048
	Average		-.0068			+.0014			-.0053
	Std Dev		.0072			.0030			.0097

Table 2: Pseudo and real dynamic heights (dyn m) for Slope Water CTD stations; values in parentheses exclude shallow casts.

Endeavor 86

Sta #	0-200 db			200-800 db			0-800 db		
	pseudo	real	diff.	pseudo	real	diff.	pseudo	real	diff.
43	.3753	.3661	+.0092	.3769	.3778	-.0009	.7522	.7439	+.0083
53	.3769	.3359	+.0410	.3153	.3168	-.0015	.6922	.6527	+.0395
54	.3322	.3168	+.0154	.3245	.3212	+.0033	.6567	.6380	+.0074
55	.3213	.3156	+.0057	.3294	.3277	+.0017	.6507	.6433	+.0017
56	.3390	.3125	+.0265	.3483	.3425	+.0058	.6873	.6550	+.0323
57	.3463	.3156	+.0307	.3486	.3503	-.0017	.6949	.6659	+.0290
58	.3222	.2962	+.0260	.3479	.3488	-.0009	.6701	.6450	+.0251
60	.3163	.3125	+.0038	.3651	.3703	-.0052	.6814	.6828	-.0014

Endeavor 88

Sta #	pseudo	real	diff.	pseudo	real	diff.	pseudo	real	diff.
47	.3943	.3846	+.0097						
65	.3564	.3448	+.0116	.3411	.3379	+.0032	.6975	.6827	+.0148
66	.3517	.3326	+.0191	.3233	.3239	-.0006	.6750	.6565	+.0185
67	.3968	.3775	+.0193	.3310	.3320	-.0010	.7278	.7095	+.0183
68	.3607	.3451	+.0156	.3387	.3391	-.0004	.6994	.6842	+.0152
69	.3121	.3171	-.0050	.3340	.3430	-.0090	.6461	.6601	-.0140
70	.3070	.3131	-.0061	.3497	.3527	-.0030	.6567	.6658	-.0091
71	.3115	.3273	-.0158						
	Average		+.0129	(.0152)		-.0007			+.0145
	Std Dev		.0146	(.0133)		.0037			.0152

Table 3: Pseudo and real dynamic heights (dyn m) for the Gulf Stream stations.

Endeavor 86

Sta #	0-200 db pseudo	0-200 db real	0-200 db diff.	200-800 db pseudo	200-800 db real	200-800 db diff.	0-800 db pseudo	0-800 db real	0-800 db diff.
44	.5422	.5122	+.0300	.4741	.4780	-.0039	1.0163	.9902	+.0261
45	.5523	.5563	-.0040	.7960	.7978	-.0018	1.3483	1.3541	-.0058
46	.5399	.5491	-.0092	.8859	.8831	+.0028	1.4258	1.4322	-.0064
50	.5305	.5386	-.0081	.9472	.9437	+.0035	1.4777	1.4832	-.0046
51	.5570	.5561	+.0009	.8020	.8027	-.0007	1.3590	1.3588	+.0002
52	.4271	.4212	+.0059	.4410	.4425	-.0015	.8681	.8637	+.0044

Endeavor 88

Sta #	0-200 db pseudo	0-200 db real	0-200 db diff.	200-800 db pseudo	200-800 db real	200-800 db diff.	0-800 db pseudo	0-800 db real	0-800 db diff.
48	.4844	.4370	+.0474	.3941	.3963	-.0022	.8785	.8333	+.0452
49	.6197	.6308	-.0111	.5510	.5534	-.0024	1.1707	1.1842	-.0135
50	.5702	.5875	-.0173	.8344	.8341	+.0003	1.4046	1.4216	-.0170
51	.4983	.5108	-.0125	.9200	.9206	-.0006	1.4183	1.4314	-.0131
60	.5355	.5376	-.0021	.9908	.9885	+.0023	1.5263	1.5261	+.0002
61	.5384	.5464	-.0080	.9409	.9391	+.0018	1.4793	1.4855	-.0062
62	.5353	.5533	-.0180	.8135	.8114	+.0021	1.3488	1.3647	-.0159
63	.5704	.5690	+.0014	.5206	.5204	+.0002	1.0910	1.0894	+.0016
64	.4428	.4010	+.0418	.3406	.3367	+.0039	.7834	.7377	+.0457
	Average		+.0025			+.0003			+.0027
	Std. Dev.		.0207			.0024			.0203

Differences between pseudo and real data are given as well as statistics for groups of stations in each of the above three regimes. Errors are largest in the upper 200 m comparing dynamic height differences, but random errors in the differences are <= 2 dynamic cm. Systematic changes in the water masses across the Gulf Stream account for the average differences between the pseudo and real data: in other words, the real T/S profiles are NOT constant across the Gulf Stream. Comparing the Slope Water and Sargasso Sea results for the differences in dynamic height, one sees an average difference (0-800 m) of 2 dyn cm, with a similar standard error, out of a total cross-stream difference of 80 cm. Thus, errors are of order 2% of the signal. In the next section, dynamic heights and calculated densities will be used to compare velocities and transports of the Gulf Stream. The FORTRAN code used to generate a pseudo salinity is given in the appendix. One possible way to improve the algorithm would be to use an observed surface salinity and an interpolation scheme for the upper 200 m. There is a slight salinity decrease between 200 m and the surface due to the injection of shelf water onto the slope by warm-core rings, and by transfer of Slope Water across the Gulf Stream by cold-core rings. This might further reduce the systematic errors across the Gulf Stream in the upper 200 m. However, as we show in fig 2, the salinity variations in the upper 200 m indicate that the fresh surface layer cap is relatively shallow making a simple *linear* interpolation between the surface and 200 m depth a questionable next step.

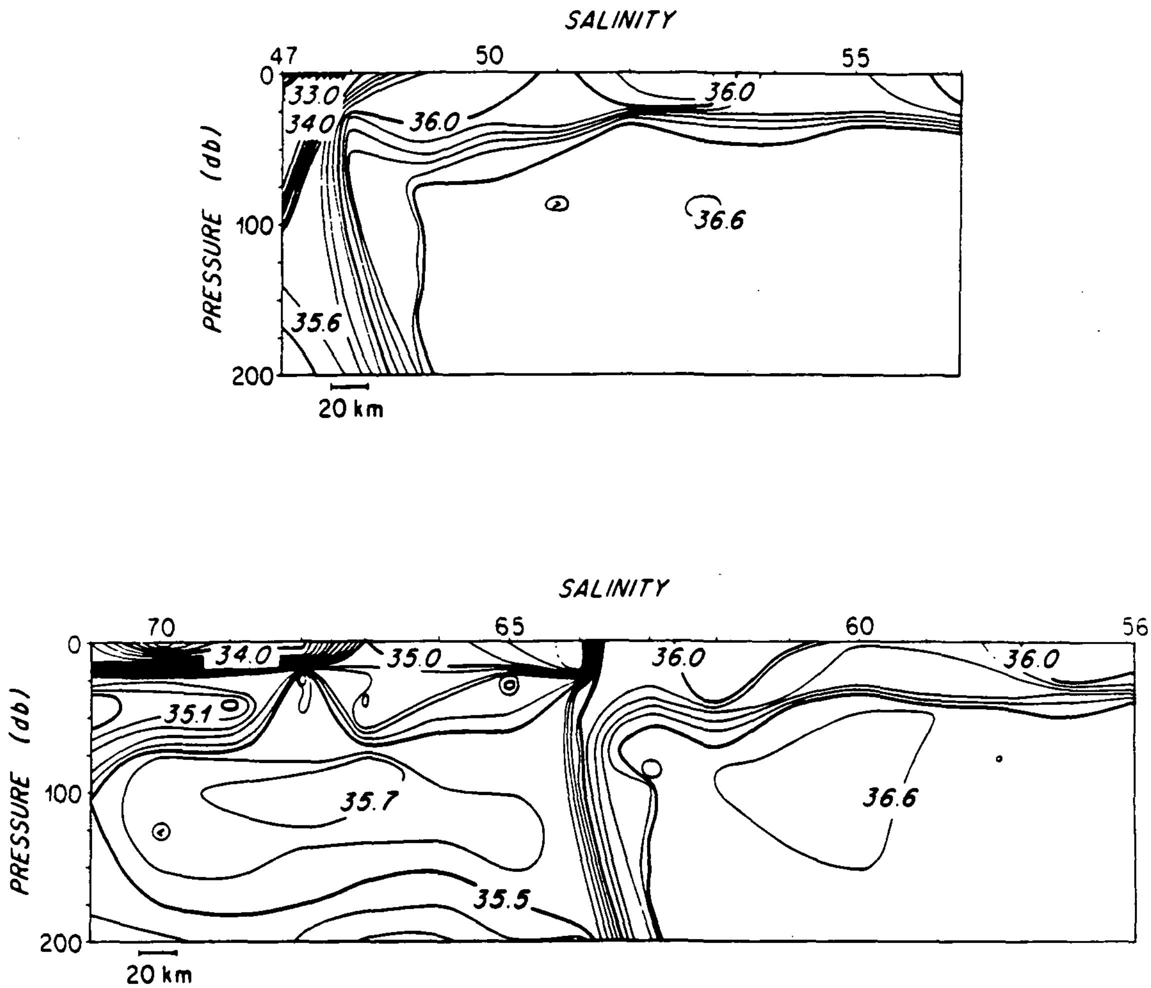

Figure 2: Salinity sections for EN88 in the upper 200 m. The upper panel is for the "south", or shorter section, while the lower panel is for the "north" section (see fig. 1).

3 VELOCITY AND TRANSPORT COMPARISONS

The "true" profiles of absolute velocity and volume transport for PJ are shown in Figure 3 for the upper 800 m with the "south" ("north") section on the left (right). The Slope Water is on the left and the Sargasso Sea on the right in both cases. The sections are approximately balanced in total transport as a result of the inverse calculation with the combined CTD/ADCP data as described above. The maximum velocity of the south section is 120 cm/s at the surface over the intersection of the 15° C isotherm and 200 m. The maximum velocity in the longer north section has increased to 140 cm/s. The total volume transport for both sections is approximately 80 Sv. The difference between the velocity and transport of the pseudo sections and the true sections is shown in Figure 4. Velocity errors are generally less than 5 cm/s and total transport errors are less than 1 Sv.

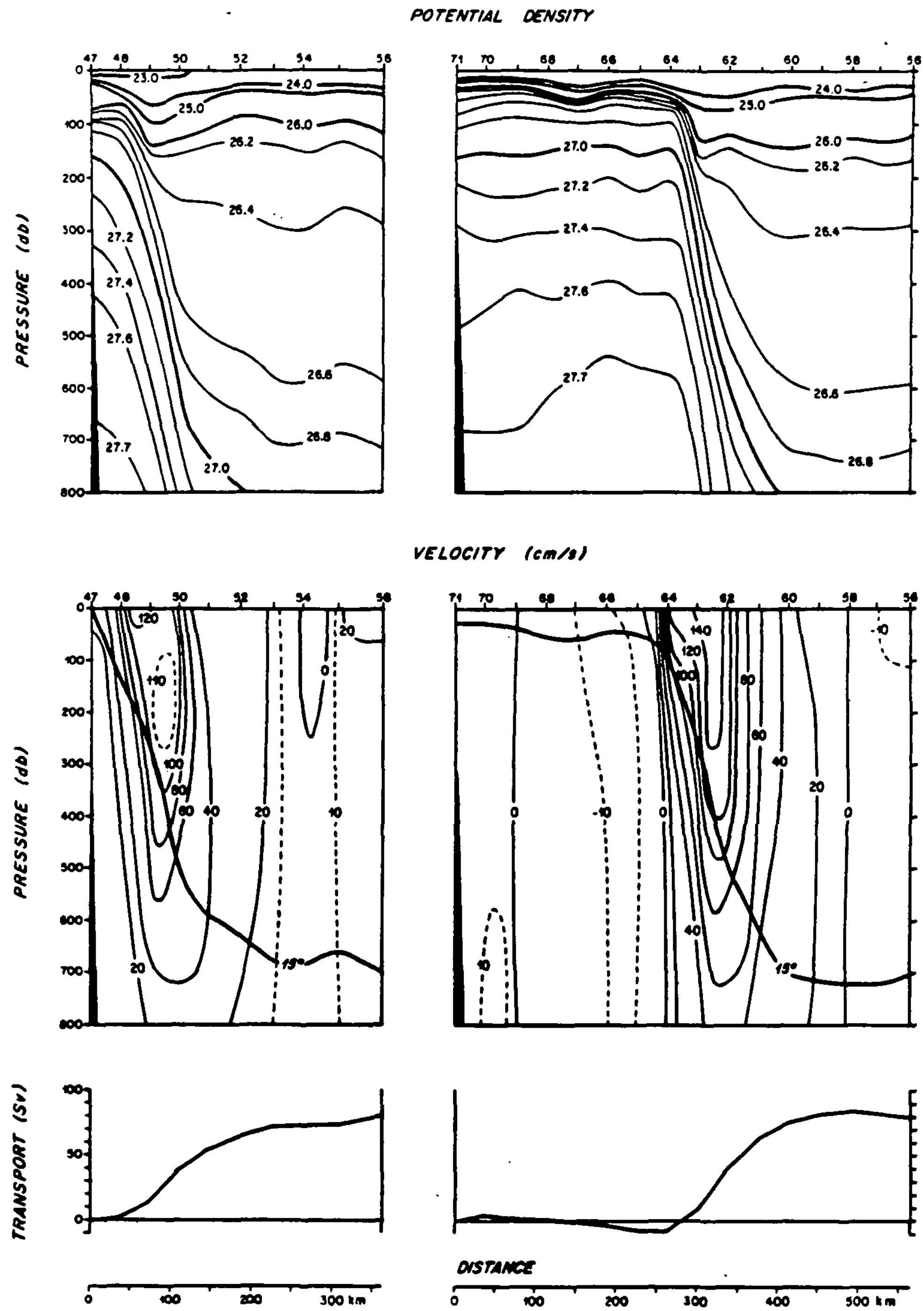

Figure 3: Density (upper panel), velocity (cm/s, middle) and integrated transport (Sv) for the "real" salinity data on the EN88 transects of the Gulf Stream.

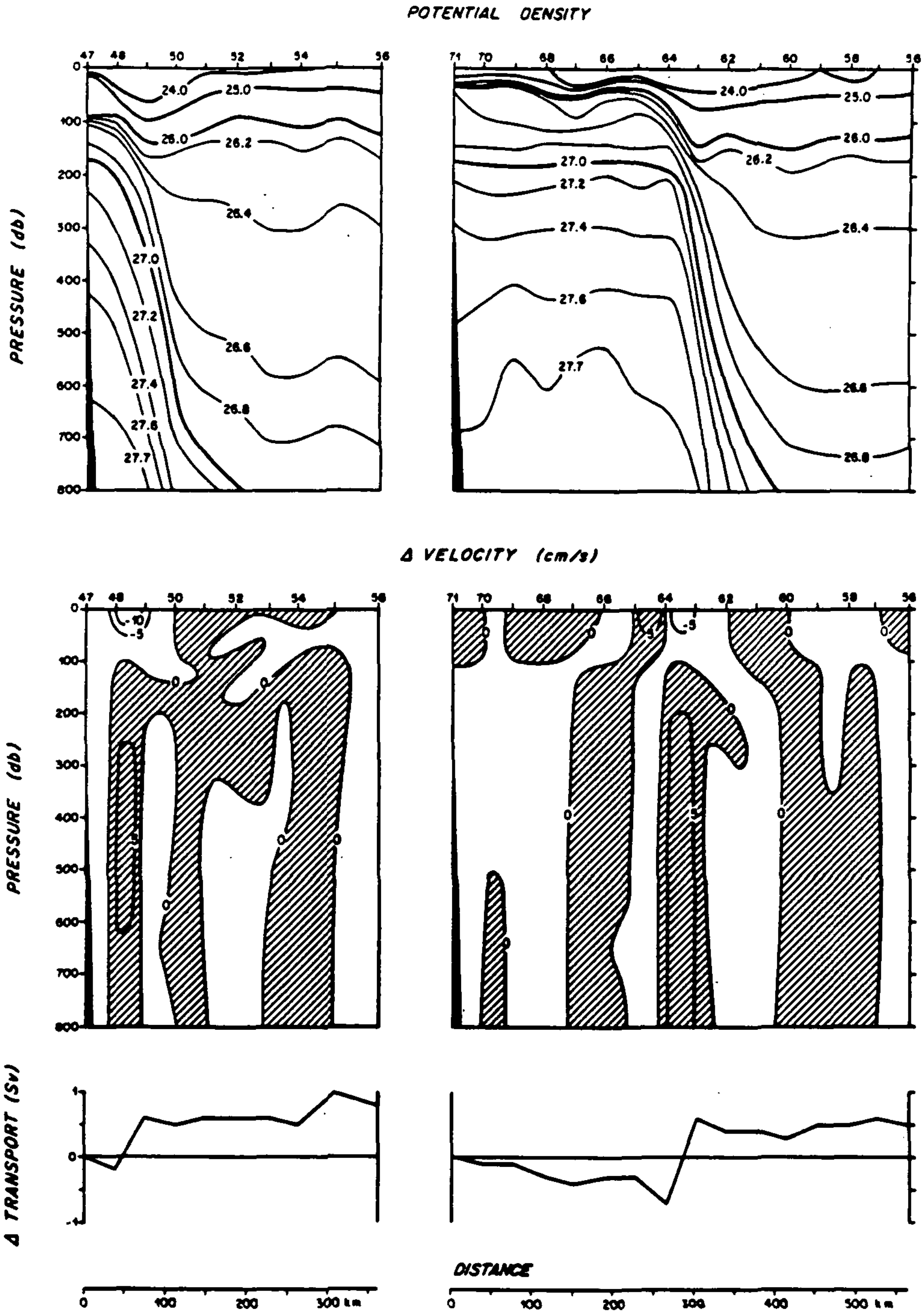

Figure 4: As in previous figure except the density is for the "pseudo" salinity data, with the velocity and integrated transport difference (pseudo-true). Positive differences are denoted by cross-hatching.

In order to examine aspects of the volume transport in different parts of the water column, the sections were divided into six layers defined by surfaces of constant potential density. These layers were chosen in an attempt to resolve the major water mass features. It should be noted that the density layers chosen for this summary are not the same as those used in the inverse calculations of PJ. Also, the present data, to be consistent with XBT limitations, do not contain any information from deeper than 800 m. If we assume that the flow is entirely along layers of constant potential density, the transport within each layer should be in approximate agreement between the north and south sections. Table 4 lists the chosen isopycnals and the corresponding volume transports for the EN 88 sections. Two different inverse solutions are shown for the true (CTD) data, one assuming a degree of linear independence of rank 33 (underdetermined solution), and one assuming a fully determined solution of rank 36. Per PJ, the difference between these solutions represents the limits of uncertainty for the inverse solution technique. The pseudo section transports based on the rank 33 solution are also shown.

The difference in total transport between the real and pseudo data is less than the difference between the rank 33 and rank 36 solutions, indicating that for overall transport calculation, the XBT data and the salinity algorithm gives results within the accuracy of the CTD data. For density sorted transport, the difference between true and pseudo section transports has approximately twice the standard deviation of the difference between the rank 33 and rank 36 transports. When north vs south section transports are compared, the pseudo section transport differences have a standard deviation only slightly higher than the true section transport differences. Figure 5 shows the section integrated transports and north-south transport differences for the selected density layers.

Table 4: Summary of transports and transport differences in isopycnal layers for real and pseudo salinity sections of EN88. Transport figures in Sv, area in km². Rank 33 and 36 reference velocities used are from PJ.

DENSITY LEVEL	AREA	SOUTH SECTION TRANSPORTS RANK 33	RANK 36	PSEUDO	TRANSPORT DIFFERENCES 33-36	33-PSEUDO
26.0	36.1	15.1	15.0	15.5	.1	-.4
26.4	47.8	13.4	13.5	13.3	-.1	.1
26.6	75.6	19.6	19.9	18.4	-.3	1.2
27.0	70.0	18.7	18.7	19.5	.0	-.8
27.6	37.2	11.4	10.5	11.8	.9	-.4
27.8	14.4	1.7	1.3	2.0	.4	-.3
TOTALS	281.1	79.9	78.9	80.5	1.0	-.6
				STD DEV	.4	.7

DENSITY LEVEL	AREA	NORTH SECTION TRANSPORTS RANK 33	RANK 36	PSEUDO	TRANSPORT DIFFERENCES 33-36	33-PSEUDO
26.0	47.3	17.3	17.1	18.5	.2	-1.2
26.4	43.4	13.0	12.7	12.8	.3	.2
26.6	72.2	19.8	19.4	17.4	.4	2.4
27.0	75.8	18.0	17.9	19.9	.1	-1.9
27.6	94.1	12.1	12.9	11.9	-.8	.2
27.8	104.1	-.1	1.1	.2	-1.2	-.3
TOTALS	436.9	80.1	81.1	80.7	-1.0	-.6
				STD DEV	.7	1.5

DENSITY LEVEL		NORTH-SOUTH TRANSPORT DIFFERENCES TRUE SECT	PSEUDO SECT
26.0		-2.2	-3.0
26.4		.4	.5
26.6		-.2	1.0
27.0		.7	-.4
27.6		-.7	-.1
27.8		1.8	1.8
	SUM	-.2	-.2
	STD DEV	1.4	1.7

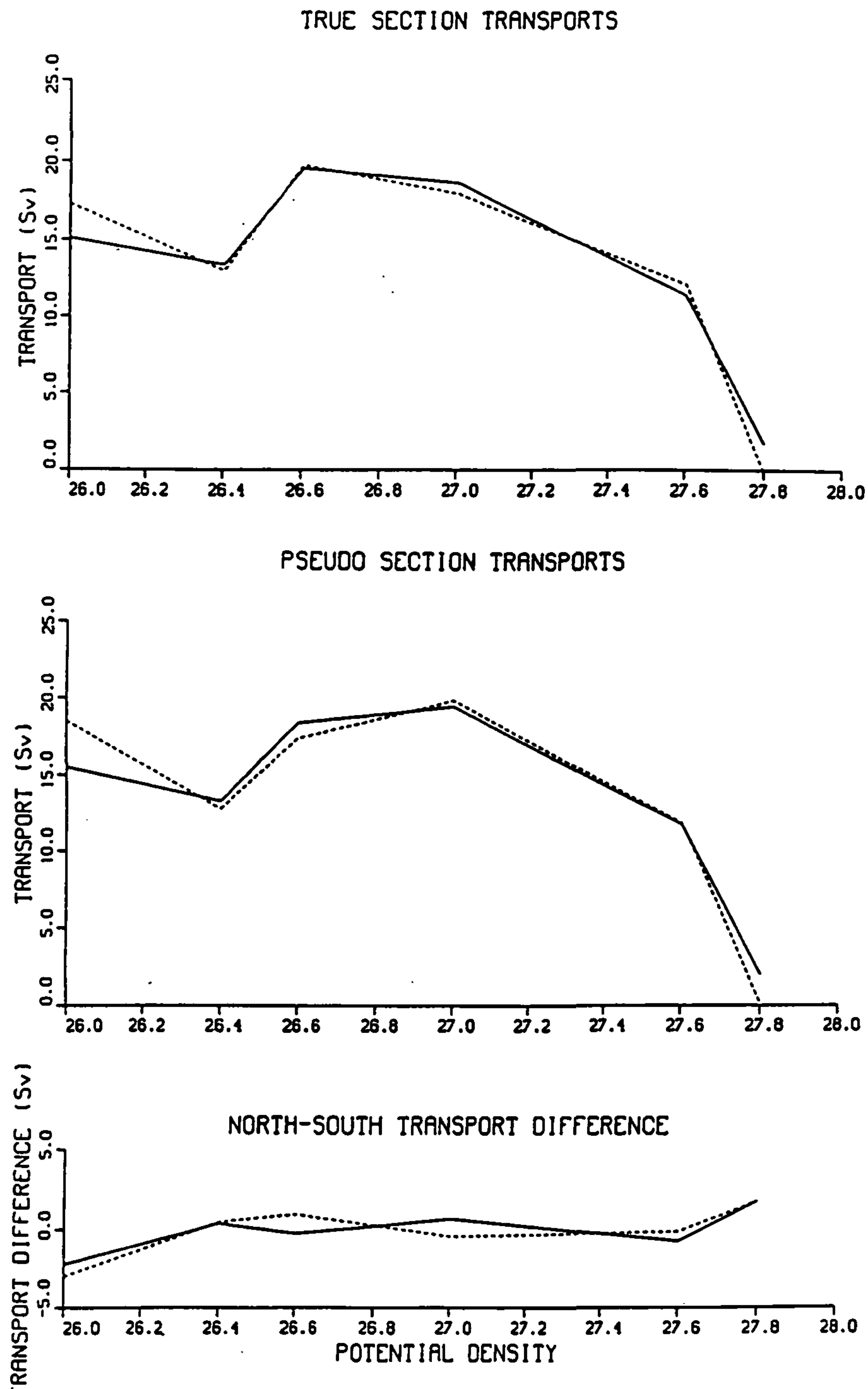

Figure 5: Section integrated transports and transport differences (north-south) for selected density layers (see Table 4). North section transports are denoted by dashed lines and south section transports are denoted by solid lines. For the transport differences, true salinities are denoted by solid lines while pseudo salinities are plotted as dashed lines.

4 DISCUSSION

A procedure has been presented that evaluates the possible combined use of XBT and ADCP data for quantitative estimates of the velocity structure and transport of the upper levels (surface-800 m) of the Gulf Stream. While inverse methods are a major element of the technique, we have not recalculated new solutions for the data and pseudo data employed. Rather, we have taken previous estimates of the "corrected" ADCP data and incorporated them into new estimates of the isopycnal transports in the upper 800 m based on temperature and depth alone. Transport errors arise in two distinct ways: dynamic height errors which result in relative velocity errors, and isopycnal layer thickness errors, which combined with the above will produce additional errors in layer volume transports.

We have shown that uncertainty in estimation of the volume transports in individual layers using the pseudo salinity data are 1.5 Sv in the upper 800 m, as opposed to 0.7 Sv uncertainty due to our limitations in determining ADCP corrections in the inverse method. An error of 0.7 (1.5) Sv in transport over a section length of approximately 500 km (the north section) and depth of 800 m results in a layer velocity uncertainty of 0.18 (0.33) cm/s for the section. These figures, if applied to the upper layer, are equivalent to sea surface slope uncertainties of 1.9 (4.1) x 10^{-8}, which as JWP discuss, are smaller than can be obtained gravimetrically (Zlotnicki, 1984). Thus, the method could be used to estimate, with satellite altimetry, the earth's geoid.

Of further interest is whether the errors may overwhelm the natural variability in the Gulf Stream, thus limiting the application of the method to the study of the time-varying transport (and sea surface slope) of the Gulf Stream. Worthington (1976) has assembled a composite of the time-varying transport relative to a reference level of 2000 db giving a mean and standard deviation of 77 and 7 Sv, respectively, with a suggestion that there is a significant seasonal component to the transport variation. A related study by Fu, Vazquez, and Parke (1986) shows temporal variations in sea surface height across the Gulf Stream of order 10 cm as estimated from Geos-3 altimeter data, again equivalent to a time-varying signal with an amplitude that is approximately 10% of the mean. The combined errors in reference velocity and layer transports above amount to about 2-3% of the total integrated signal. Therefore, the method should be able to resolve the temporal variations in Gulf Stream transport with a "signal/noise" ratio of approximately 4. It could also determine the variation in transport as a function of density, at least for those layers with substantial volume transport in the upper 800 m.

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Appendix A

Program listings

A.1 Program description

NAME: DUMYSALT

TYPE: Main program.

PURPOSE: Read in CTD data and overwrite salinities using historical temperature/salinity relationship for the NW Atlantic (Armi-Bray/Worthington-Metcalf).

MACHINE: VAX-11

SOURCE LANGUAGE: FORTRAN 77

PROGRAM CATAGORY: Data manipulation

DESCRIPTION: A nominal salt value, bottom pressure and salinity are used to calculate a potential temperature(theta). The theta value is then used to calculate a new salinity (function THSAL, representation of Worthington-Metcalf). The program works from the bottom to the surface (or user specified pressure level) with each newly calculated salinity used as input for the next theta, salinity calculation. From the user-specified pressure level to the surface, the salinities remain constant unless the current temperature is less than the previous temperature minus a user specified delta (the current temperature must also be less than a nominal shelf water/slope water value, currently set at 12 deg.). If the temperature criteria are met, a linear interpolation is done, using temperature, from the last salinity to a reference salinity of 32.5 and temperature of 8. degs.

INPUT: CTD data in VAX format. The data must be stored in a standard ctd-type subdirectory.

OUTPUT: CTD data in vax format. User specifies cast number; station number remains the same ,data type is assigned an 'f' (fake).

USAGE: User is queried for an initial nominal salinity value, a minimum allowable temperature change, and a pressure level (above which all salts are the same).

A.2 Program to generate salinity

```
      PROGRAM DUMYSALT
C
C   THIS PGM WAS CTDED. IT NOW READS IN CTD DATA, AND OVERWRITES
C     SALINITIES WITH THETA BRAY-ARMI SALTS (REPRESENTATION OF
C     WORTHINGTON-METCALF).
C
C     USER ENTERS INITIAL SALT VALUE, CALCULATES THETA FROM BOTTOM
C     PRS & TEMP AND NOMINAL SALT. THEN, THETA IS USED WITH BOTTOM
C     P & T AND A NEW SALT VALUE IS CALCULATED FOR THE BOTTOM SALT.
C     A BOTTOM VALUE THETA IS CALCULATED, AND THEN USED TO CALCULATE
C     BOTTOM-2 SALT.TMJ & JAD
C$LINK DUMYSALT,PLEVEL,CTDA:<CTDEV.LIST>GRADPROP,CTDOPENW,-
C<CTDEV.GETDAT>PUTDAT1,<CTDEV>ISW1,SEAPROP/LIB,-
C<CTDEV.GETDAT>CTDATA/LIB,BIGA:[WCRSOFT.NODC]CREAD,-
CNODC/LIB,CTD80SUB2,PHYPROPSW/LIB
C
      CHARACTER*4 IDVICE
C
      INCLUDE 'CTDA:<CTDEV.GETDAT> IDXREC.DIM'
C
      COMMON /RAWDATA/ P(6000),T(6000),S(6000)
C
      DIMENSION ENG(10)
      DIMENSION DATA(3300,0:15)
C
C   HAVE TO INCREASE SCAN LENGTH FOR XTRA VARS
C
      DIMENSION TEMP(3300),SALT(3300),OXYGN(3300),QUALY(3300)
      DIMENSION PRESS(3300)
C
      INTEGER EDVERS(4)
      INTEGER OLDNTOT,EDSCAN
      INTEGER IDAY(3),ITME(2)
C
      REAL TTEMP,STEMP,NPMIN,NPMAX
C
```

```
      EQUIVALENCE (TEMP(1),DATA(1,1)),(SALT(1),DATA(1,2))
      EQUIVALENCE (OXYGN(1),DATA(1,3)),(PRESS(1),DATA(1,0))
C
      BYTE DATVER,PROVER,IAGAIN,NO
C
C
      DATA EDVERS/2HED,2H88,2H08,2H88/
      DATA SNOMINAL/35.00/
      DATA PLESS/200./
      DATA NO/'N'/
      DATA DT,TM/.5,0.0/
      DATA SWSS/12./
      DATA NOBS/3300/
      DATA FLAG/0/
C
C ****************************
      WRITE(6,*)'        PGM DUMYSALT   ver 4 August 1988'
      WRITE(6,*)' '
C
      WRITE(6,*)' ENTER INITIAL NOMINAL SALT VALUE (DEF=35.0)'
      READ(5,*)SNOMINAL
      CONTINUE
C
      WRITE(6,*)' ENTER MIN TEMP CHANGE FOR DECREASING TEMP (DEF=.5)'
      READ(5,*)DT
      CONTINUE
C
      WRITE(6,*)' ENTER PRS (ABOVE WHICH ALL SALTS ARE THE SAME)'
      WRITE(6,*)'              (DEF=200)'
      READ(5,*)PLESS
C
C
      WRITE(6,*)'  ENTER DEVICE (/ FOR DEFAULT)'
      READ(5,1000) IDVICE
      IF(IDVICE(1:1).EQ.'/') IDVICE = '    '
      CALL DEVCE(IDVICE)
C
      PRINT *,'   ENTER SHIP,SUBDIRECTORY VERSION CHARACTER'
      READ(5,1005) ISHIP,PROVER
      IF(PROVER.EQ.' ') PROVER = 'D'
      CALL PVER(PROVER)
C
      PRINT *, ' ENTER CRUISE,PROJECT '
      READ(5,*) ICRUIS,IPROJ
      CALL CRUISE(ISHIP,ICRUIS,IPROJ)
C
C OPEN SUBINDEX FILE
      CALL INDEX(11)
      LREC=LSTREC
C
C
C **MAIN LOOP**
C
   10 CONTINUE
```

```
C
      IF(IFLAG.EQ.1)THEN
        WRITE(6,*)' ANOTHER STATION? (Y/N)'
        READ(5,1000)IAGAIN
        IF(IAGAIN .EQ. NO) GO TO 2000
      END IF
C
      WRITE(6,*)'   ENTER INPUT DATA VERSION CHARACTER'
      READ(5,1000) DATVER
      CALL DVER(DATVER)
C
      PRINT *,  ' ENTER STATION,CAST '
      READ(5,*) ISTAT,ICST
      CALL STATION(ISTAT,ICST,10)
C
 222  CALL GETDAT(10,DATA,NOBS,MSCAN)
C
C
      ISTART=1
      IEND=NTOT
      PMAX=PRESS(NTOT)
C
      PMIN=PRESS(1)
      CALL PVERP(PROVER)
      CALL CRUISEP(ISHIP,ICRUIS,IPROJ)
C
C OPEN OUTPUT DATA FILE
C
      DATVER='F'
      CALL DVERP(DATVER)
      PRINT *,  ' ENTER OUTPUT CAST # '
      READ(5,*) ICAST
      CALL STATONP(ISTAT,ICAST,15)
C
        NPMIN=PMIN
        NPMAX=PRESS(NTOT)


C******************** REDEFINE PMIN FOR UP PROFILE*****
      PMIN=PRESS(1)
      IF(PRSINT.LT.0.0) THEN
      PRINT *,'  UP PROFILE CONVERSION TO DOWN FORMAT'
      PRSINT=ABS(PRSINT)
      END IF
C
C
      CALL PUTINT(15,MSCAN)
C
C SALINITY RECALCULATED
C
      DO 175 J=IEND,ISTART,-1
        PP=PRESS(J)
        SS=SNOMINAL
        TT=TEMP(J)
```

```
        IF(PP .GE. PLESS .OR. J .EQ. IEND )GO TO 170
        IF(TT .LE. (TM-DT) .AND. TT .LE. SWSS)THEN
          SN=32.5+(SM-32.5)*(TT-8.)/(TM-.8)
          GO TO 172
        ELSE IF(TT .LE. TM)THEN
          GO TO 172
        ELSE IF (TT .GT. TM)THEN
          TM=TT
          SN=SM
          GO TO 172
        END IF
170     SN=THSAL(THETA(SS,TT,PP,0.))
        TM=TT
        SM=SN
172       SALT(J)=SN
        SNOMINAL=SN
175   CONTINUE
C
C
      DO J=ISTART,IEND
       DO K=1,MSCAN
        ENG(K)=DATA(J,K)
       END DO
        CALL PUTDAT(ENG,ISTAT1)
      END DO
C
      ENG(1)=-999.
      CALL PUTDAT(ENG,ISTAT1)
C
C  NEED UTILITY TO ASSIGN VARIABLE DESCRIPTORS
C
      LPGVER(1)=EDVERS(1)
      LPGVER(2)=EDVERS(2)
      LPGVER(3)=EDVERS(3)
      LPGVER(4)=EDVERS(4)
      VARDES(3,KSCAN)=NPMIN
      VARDES(4,KSCAN)=NPMAX
C
      OLDNTOT=NTOT
      OLDPMIN=PMIN
      NTOT=NELEM(NPMAX)-NELEM(NPMIN)+1
      PMIN=NPMIN
      CALL IDXRECP
      NTOT=OLDNTOT
      PMIN=OLDPMIN
C
C FLAG SET, BACK TO MAIN LOOP
C
      WRITE(6,1010)ISTAT,DATVER,ICAST
      IFLAG=1
      GO TO 10
C
C **FORMATS**
C
```

```
 1000 FORMAT(A)
 1005 FORMAT(A2,X,A1)
 1010 FORMAT(' STATION',I4,' VERSION ',1A,' CAST',I4,'  - COMPLETED')
C
C
 2000 CONTINUE
      WRITE(6,*)' END PROGRAM DUMYSALT'
      STOP
      END
```

A.3 Salinity from T/S relation

```
C THSAL FCN ******** JULY 6 1977 *******************
C   BY NAN BRAY
      FUNCTION THSAL(T)
C
C TAKES UP TO 25 CUBIC SPLINES TO GENERATE A SALINITY FROM
C POTENTIAL TEMPERATURE REFERRED TO THE SURFACE..INPUT DATA
C CONSISTS OF LOWER SPLINE BOUNDARY FOLLOWED BY FOUR COEFFICIENTS.
C INITIAL COEFFICIENTS ARE FROM L. ARMI'S FIT TO ISELIN AND
C WORTHINGTON METCALF THETA-SAL DATA.
C
      DIMENSION C(5,25)
C DATA
      DATA C/0.00,34.738063,0.0,0.0,0.0,
     *0.50,34.738053,.107290,.584849E-02,-.253429E-02,
     *1.20,34.815152,.111753,.523726E-03,.582151E-01,
     *1.50,34.850297,.127785,.529320E-01,-.135379,
     *1.75,34.883436,.128868,-.485828E-01,-.129913,
     *2.00,34.910587,.802174E-01,-.146093,.228920,
     *2.25,34.925087,.500936E-01,.255484E-01,-.267382E-01,
     *2.50,34.938790,.578544E-01,.552526E-02,-.359945E-01,
     *2.75,34.953036,.538681E-01,-.214953E-01,-.374594E-01,
     *3.00,34.964575,.360969E-01,-.495364E-01,.509274E-01,
     *3.20,34.970220,.223936E-01,-.189292E-01,.580683E-01,
     *3.40,34.974406,.217901E-01,.157868E-01,.479730E-02,
     *3.60,34.979434,.286805E-01,.185975E-01,-.294172E-01,
     *3.80,34.985679,.325895E-01,.102958E-02,-.279688E-01,
     *4.00,34.992014,.296450E-01,-.157123E-01,.643397E-02,
     *5.00,35.01238,.175223E-01,.357759E-02,.114377E-02,
     *7.00,35.07089,.455579E-01,.104386E-01,.865592E-05,
     *10.00,35.30174,.108423,.105172E-01,-.763343E-03,
     *13.00,35.70106,.150916,.364790E-02,.310805E-04,
     *16.00,36.18748,.173643,.392926E-02,-.689782E-02,
     *19.00,36.557,  .032,        -.9142857E-2,0.,
     *20.75,36.585,  0.,          -.512E-2,     0.,
     *22.00,36.577,  -.01175,     -.875E-3,     0.,
     *26.00,36.516,  0.,          0.,           0.,
     *5*0/
C
      DATA KNOTS/22/
C
```

```
250 X = 0.0
    DO 310 I=1,KNOTS
    DT = C(1,I) - T
    IF(DT)305,320,320
305 X = -DT
310 CONTINUE
320 D = X
    ID = I-1
    IF(ID)325,325,330
325 ID = 1
    D = 0.0
330 THSAL =((C(5,ID)*D+C(4,ID))*D+C(3,ID))*D+C(2,ID)
    RETURN
    END
```