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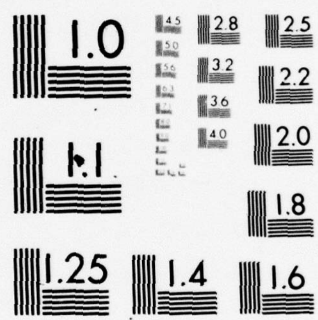

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TECHNICAL NOTE

SELECTION OF WATER MASS HISTORY FROM BATHYTHERMOGRAM CHARACTERISTICS

by

ALVAN FISHER, Jr.

JUNE 1976

U. S. NAVAL OCEANOGRAPHIC OFFICE
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Discuses the use of a historical data file based on water mass concepts to automatically select (by computer program) one of several possible histories based on characteristics of the input bathythermogram.

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ABSTRACT

A historical data file based on the near-surface water masses of the North Atlantic Ocean is discussed. The most attractive feature of the water mass file is that the characteristics of the input bathythermogram will objectively determine the proper deep history for computation of the surface to bottom sound speed profile. A second feature is the adjustment of salinity to the presence of temperature inversions (sound channels) to maintain a stable water column. Evaluation of the water mass file using salinity-temperature-depth (STD) data shows that is is superior to the file presently used in the Integrated Carrier Antisubmarine Warfare Prediction System (ICAPS).

ERRATA

Tables 1, 2, and 3: Columns headings should be changed from "RMS SD" to "Mean RMS".

ACKNOWLEDGEMENTS

Space does not permit recognition of all those who contributed to the creation of the water mass file since its inception several years ago. Among those providing substantial assistance are A. W. Ortolano and L. Riley (data processing); W. H. Beatty, III (evaluation); and L. A. Defibaugh and A. G. Voorheis (manuscript preparation). The project was funded as part of the Integrated Carrier Antisubmarine Warfare Prediction System (ICAPS) under the cognizance of the U. S. Naval Oceanographic Office.

INTRODUCTION

Sound speed profiles extending from sea surface to ocean floor are a necessary input to sonar range prediction models. Because synoptic sound speed profiles rarely are available to fleet operating units, synthetic profiles are constructed either by combining a synoptic bathythermograph trace with deep historical oceanographic data (Mendenhall; Faucher, et al; Hanssen and Tucker) or by historical data alone (Russell; Podeszwa). Each of the several techniques available relies on a different method of generating the surface to bottom sound speed profiles. They agree, however, in that they provide a single seasonal profile for each region; with each region having fixed boundaries. Unfortunately, real-world oceanographic features are constrained only by bathymetric boundaries, and their position may vary rapidly as in the case of a Gulf Stream meander or cyclonic eddy. Thus historic files based upon a single regional history frequently provide misleading sonar range predictions. The purpose of this report is to describe a historic oceanographic data file -- based on water mass concepts -- in which the computer program uses the characteristics of the input bathythermograph trace to automatically select one of several possible histories. The file was designed to be incorporated into the Integrated Carrier Anti-submarine Warfare Prediction System (ICAPS) developed under the cognizance of the U.S. Naval Oceanographic Office (NAVOCEANO).

Two premises were made while developing the new file: (1) that near surface water masses can be uniquely identified by thermohaline characteristics and (2) the thermal characteristics of neighboring water masses are sufficiently different so as to permit reliable identification from an expendable bathythermograph (XBT) trace alone. After identification of the applicable deep history, temperature values of the input trace are merged with deep temperatures using an equation of the form

$$T_i = Th_i + K_i \; (K_{i-1} \Delta T)$$

where T_i and Th_i are, respectively, estimated and historical temperatures at depth i, K a weighing factor, and ΔT the difference between temperature at the bottom of the XBT trace and interpolated historical temperature at the same depth. The weighing factor, developed from imperical solution for a set of historical data, is determined as a function of the depth increment between points

$$K_i = 0.835^{(D_i - D_{i-1})/100}$$

At the first symthesized temperature value (i = 1), K_{i-1} equals unity.

PROCEDURE

Because few guidelines for water mass identification are available in classical oceanographic literature, it was decided that the most objective method of determining water mass characteristics within a given area was to look at original oceanographic data. Two world-wide data files were available for this purpose: (1) an oceanographic station data file of approximately 491K observations compiled by the National Oceanographic Data Center (NODC) provided temperature and salinity data at each of 32 standard depths between the sea surface and 7,000 meters (m) and (2) an expendable bathythermograph (XBT) file of approximately 218K observations compiled from three sources (NAVOCEANO, NODC, and the Fleet Numerical

Weather Center) provided temperature data at each flecture point over the depth range of the instrument (as deep as 760 m). The following procedure was used to determine water mass characteristics in the near-surface layer (0-400 m):

A. The classical literature was searched for applicable descriptive papers. For example, the northern edge of the Gulf Stream is frequently delineated by the 15°C isotherm at 200 m.

B. The ocean station data file was used to provide annual composite statistical data (mean, standard deviation, number of observations) at each standard depth using all available data within the area of interest. A plot of the distribution of temperature versus salinity, plotted at both 200 and 400 m, provided insight as to the number of water masses present and thermohaline variability within each water mass. Figure 1 shows a plot of temperature versus salinity at 200 m in the rectangle 45 to 50°N, 40° to 50°W -- an area where the cold Labrador Current meets with the warmer North Atlantic Drift. The presence of water masses with specific thermohaline characteristics are clearly recognizable, and tentative water mass classification has been made. The 200 m level was found to be an ideal depth for classification in that it is generally well below the level of both diurnal and seasonal changes while being within the depth range of both XBT and AXBT (airborne deployed XBT) probes. The XBT file provided statistical data and histograms for temperature and temperature gradients at preselected depths to supplement the ocean station data when necessary.

C. Flecture points in the temperature versus salinity (T-S) plot shown in Figure 1 clearly defined water mass criteria in areas where different water masses exist in close proximity. Considerable temperature

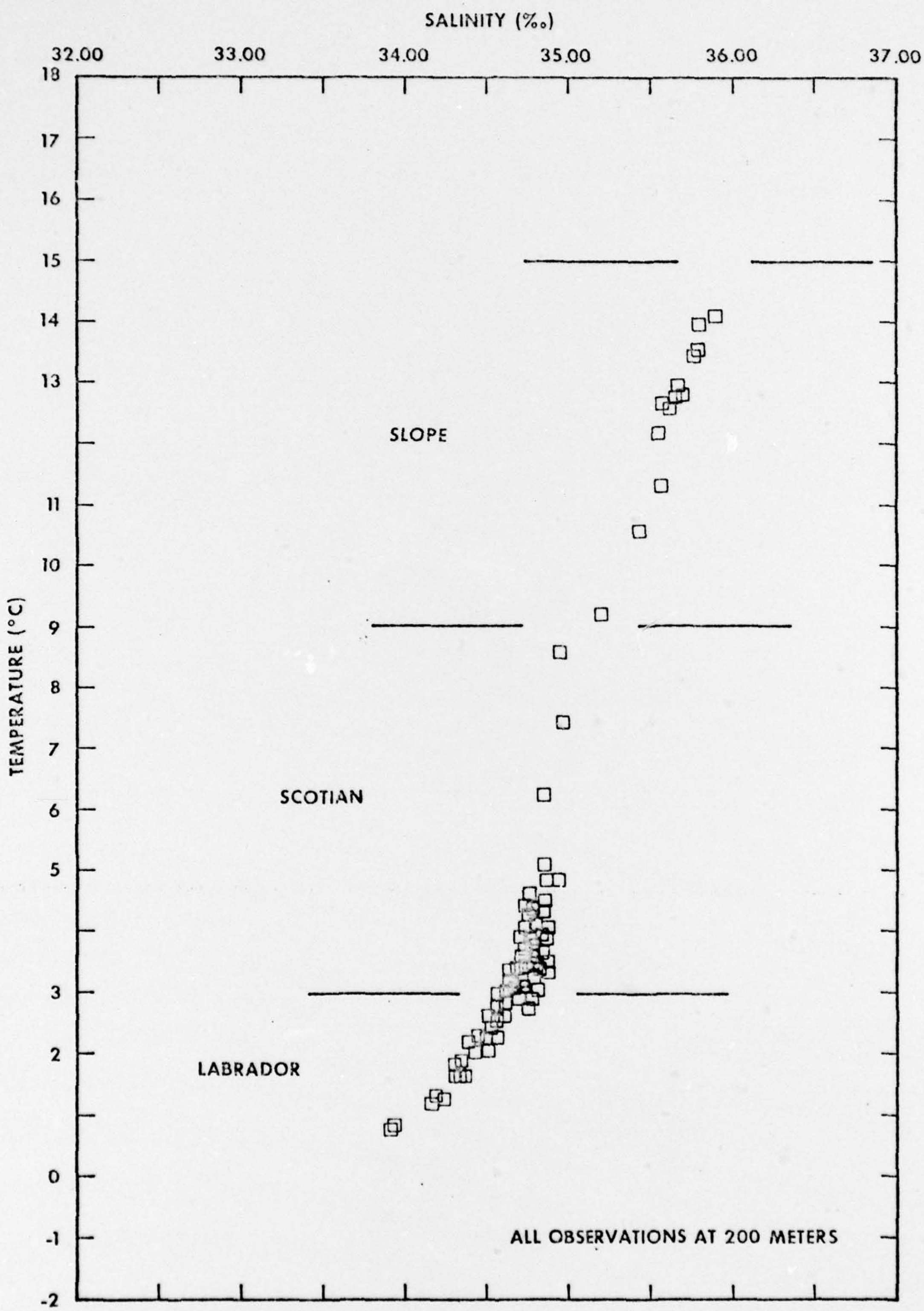

Figure 1. Distribution of temperature versus salinity, 45-50°N 40-50°W

variability also occurs in areas occupied by a single water mass, probably a result of dynamic events such as upwelling. Where variability of this nature was observed, two classifications ('warm' and 'cold') were made to provide a better merge between XBT trace and history.

D. Temperature filters at 200 m were developed to distinguish adjacent water masses based on information provided in the previous step. Where adjacent water masses had similar temperature range at the test depth, differentiation was made by examination of the temperature gradient between the 200 and 300-m levels. For example, both the Gulf Stream and the Sargasso Sea are characterized by a temperature range of from 15° to 25°C at 200 m. A near-isothermal layer of 18°C water is found to extend from the bottom of the seasonal thermocline to depths exceeding 300 m in the Sargasso Sea. No such layer exists in the Gulf Stream. Examination of Sargasso water in a region well removed from the Gulf Stream (30°-35°N; 60°-65°W) showed that 95 percent of the observations had a temperature gradient between 0.0°/100 m and -1.6°C/100 m. Thus a gradient of -1.6°C/100 m at the 200-300 m level is used in the region of the Gulf Stream to differentiate Sargasso Water from Stream Water.

E. Mean seasonal temperature and salinity values were then determined for each depth and water mass (figure 2). Where the data are not sufficiently deep temperature and salinity were extrapolated to the bottom by comparison with neighboring profiles. Inconsistencies in the data -- such as temperature inversion at depths below 200 m -- were examined to determine if they are a result of statistical processing, data distribution, or bad data.

DEPTH	TEMPERATURE MEAN	TEMPERATURE S.D.	TEMPERATURE NUM	SALINITY MEAN	SALINITY S.D.	SALINITY NUM
0	23.77	2.28	676	34.34	1.10	684
10	23.10	2.65	682	34.55	.97	680
20	21.72	3.70	682	34.84	.83	680
30	19.42	4.36	683	34.96	.83	679
50	15.87	4.17	683	35.14	.76	678
75	14.49	2.86	683	35.41	.55	678
100	13.78	2.04	683	35.54	.38	678
125	13.16	1.57	684	35.54	.28	678
150	12.54	1.34	684	35.51	.22	678
200	11.21	1.24	684	35.38	.17	676
250	9.86	1.23	684	35.24	.15	674
300	8.68	1.25	682	35.14	.13	674
400	6.87	1.10	582	35.03	.10	575
500	5.67	.79	551	34.99	.06	546
600	5.03	.52	529	34.98	.05	525
700	4.67	.32	518	34.98	.04	514
800	4.43	.24	473	34.97	.03	471
900	4.27	.20	438	34.97	.03	436
1000	4.13	.17	393	34.96	.03	386
1100	4.02	.15	350	34.96	.04	345
1200	3.92	.13	330	34.96	.04	324
1300	3.85	.12	322	34.96	.04	316
1400	3.78	.12	319	34.95	.04	313
1500	3.72	.12	315	34.95	.04	311
1750	3.56	.09	270	34.95	.04	264
2000	3.41	.09	239	34.95	.04	233
2500	3.00	.11	160	34.94	.03	154
3000	2.59	.16	89	34.92	.03	84
4000	2.26	.07	41	34.90	.02	38

SLOPE WATER (35-42N,60-76W) - SUMMER

TEMP RANGE = 9.00 - 15.00, SAL RANGE = 30.0 - 40.0

Figure 2. Temperature and salinity at standard depths in Slope Water

F. A quality control check was made by plotting the seasonal data on a single plot of temperature versus salinity (figure 3). Inconsistancies in the data are immediately apparent; temperature errors by a vertical spike, salinity errors by a horizontal spike, and depth errors by a skewed spike. Where data were obviously incorrect the plot was smoothed to conform with surrounding data.

EVALUATION

The file was evaluated by comparing the merged profile generated by both the new water mass file and the old file -- which is based on a single seasonal profile for each 5-degree rectangle -- with oceanographic data. Test data typical of each water mass within the test areas were selected from salinity-temperature-depth (STD) observations on file at either NODC or the Coast Guard Oceanographic Unit. Six observations per season, divided equally among water masses, were selected for each area. The uppermost portion (0-400 m) of the STD cast was treated as an XBT and the temperature trace extended to 1,500 m by merging with both old and new history files. Salinity was estimated and sound speed computed for all depths between the surface and 1,500 m. In the surface layer, estimated salinity and sound speed values were compared with observed values for each depth on the simulated XBT trace. In the deep layer (400-1,500 m) estimated temperature, salinity, and sound speed values were compared with observed values at 6 depths: 500, 600, 800, 1000, 1200, and 1500 m.

The first test was designed to test the premise that quality controlled data from a large area -- in this case, a 5 x 10-degree rectangle -- would compare favorably with the smaller area without quality controlled data as used to compile the old history. Should this premise prove correct, then

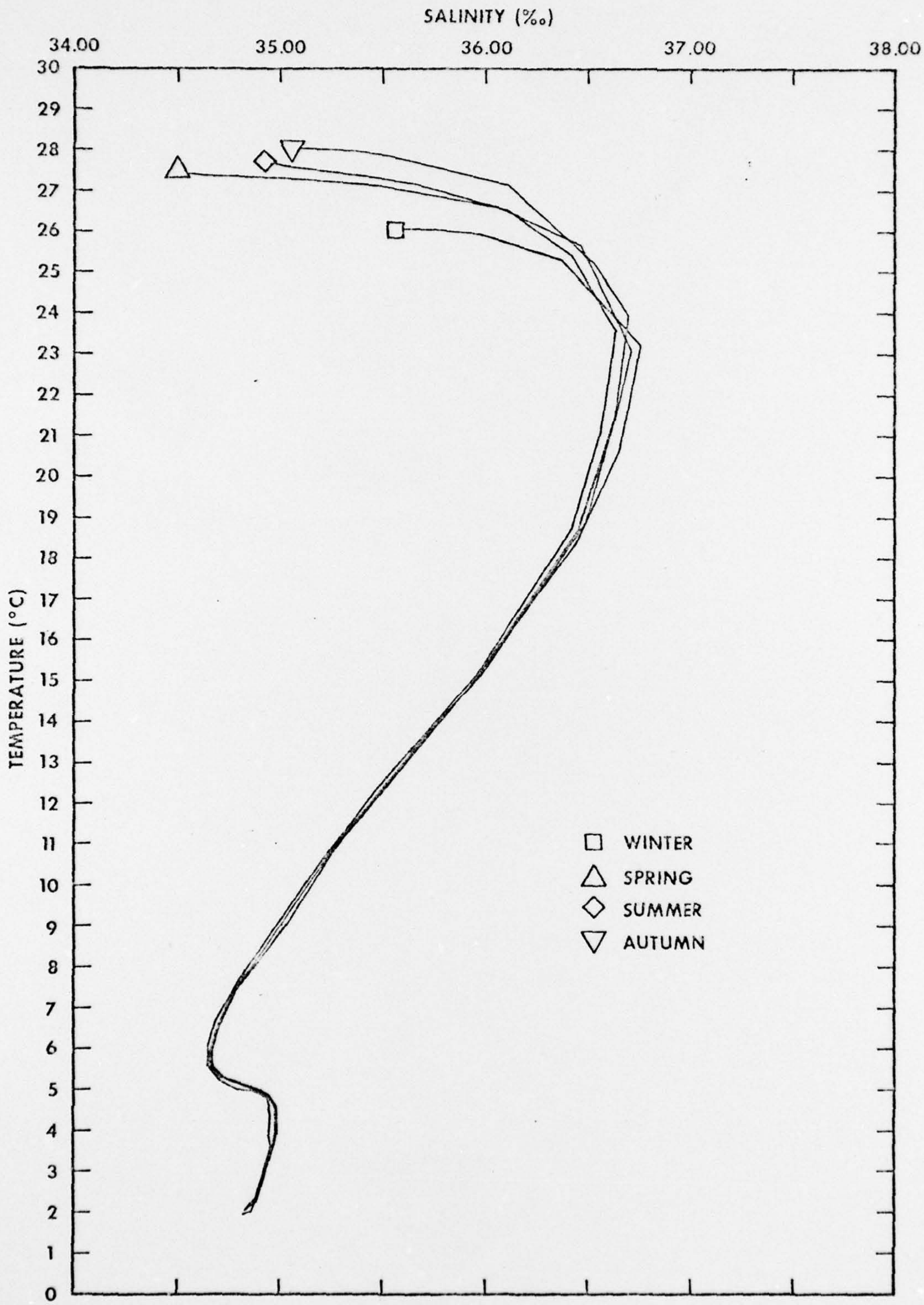

Figure 3. Seasonal plots of temperature versus salinity, 10-20°N 45-61°W

considerable reduction could be made in the file size. The area including Ocean Weather Station ECHO (44°N,48°W) was selected because considerable STD data were available from an area of relatively little oceanographic variability. The results of the test at OWS ECHO are given in Table 1. The new water mass file provided slightly better results in both the surface and deep layers.

The second test was designed to document the ability of the new file to differentiate between mater masses, thereby providing a merged profile superior to that produced by the old file. An area of high oceanographic variability seaward of the Virginia Capes (VACAPES) was selected because of the presence of 3 water masses: Slope Water, Gulf Stream Water, and Sargasso Water. Results of this test (Table 2) show that the water mass file estimates salinity significantly better in the surface layer with a corresponding increase in the accuracy of sound speed computations. The deep data again are slightly better when estimated by the water mass file than with the old file.

The final test evaluated the ability of the water mass file to adjust salinity values in a near-surface temperature inversion (sound channel). Persistence of sound channels for months at a time show that they are stable oceanographic features. However, use of unadjusted historical salinity values causes an apparent unstable water column. Thus historical salinities must be reduced by the method given in the appendix if they are to be realistic.

Salinity adjustment was evaluated in Slope Water in the VACAPES area where well-defined inversions occur from April through October. Salinity

LAYER/SEASON	N	TEMPERATURE (°C) OLD RMS	OLD SD	NEW RMS	NEW SD	SALINITY (°/oo) OLD RMS	OLD SD	NEW RMS	NEW SD	SOUND SPEED (m/s) OLD RMS	OLD SD	NEW RMS	NEW SD
Surface													
Winter	86					0.22	0.22	[illegible]	0.22	0.3	0.3	0.3	0.3
Spring	84					0.33	0.25	0.24	0.21	0.5	0.4	0.4	0.3
Summer	79					0.39	0.50	0.36	0.42	0.6	0.8	0.5	0.6
Autumn	79					0.27	0.10	0.24	0.16	0.4	0.1	0.3	0.2
Annual	328					0.30	0.31	0.26	0.28	0.4	0.5	0.4	0.4
Deep													
Winter	36	0.63	0.63	0.75	0.66	0.21	0.20	0.22	0.20	2.5	2.5	3.0	2.6
Spring	36	0.63	0.62	0.56	0.56	0.17	0.16	0.15	0.14	2.4	2.4	2.2	2.2
Summer	36	0.83	0.61	0.63	0.50	0.23	0.17	0.14	0.11	3.1	2.3	2.4	1.9
Autumn	36	0.76	0.70	0.69	0.69	0.16	0.16	0.17	0.16	2.9	2.7	2.6	2.6
Annual	144	0.71	0.65	0.66	0.61	0.19	0.18	0.17	0.16	2.7	2.5	2.6	2.4

Table 1. Root mean square difference and standard deviation between observed values and estimated values using present history (old) and water mass history (new) at OWS ECHO

LAYER/SEASON	N	TEMPERATURE (°C) OLD RMS	TEMPERATURE (°C) OLD SD	TEMPERATURE (°C) NEW RMS	TEMPERATURE (°C) NEW SD	SALINITY (°/₀₀) OLD RMS	SALINITY (°/₀₀) OLD SD	SALINITY (°/₀₀) NEW RMS	SALINITY (°/₀₀) NEW SD	SOUND SPEED (m/s) OLD RMS	SOUND SPEED (m/s) OLD SD	SOUND SPEED (m/s) NEW RMS	SOUND SPEED (m/s) NEW SD
Surface													
Winter	82					1.90	1.66	0.72	0.50	2.2	1.9	0.8	0.6
Spring	74					2.34	2.41	0.54	0.48	2.6	2.7	0.7	0.6
Summer	83					2.52	3.20	0.74	0.32	2.8	3.7	0.8	0.2
Autumn	95					1.53	1.09	0.42	0.36	1.8	1.3	0.5	0.4
Annual	334					2.05	2.83	0.60	0.44	2.3	2.6	0.7	0.5
Deep													
Winter	36	1.64	1.57	1.10	1.02	0.50	0.45	0.22	0.19	6.0	5.8	4.0	3.7
Spring	36	1.56	1.49	1.80	1.70	0.32	0.32	0.28	0.25	6.0	5.7	7.0	6.6
Summer	36	1.32	1.01	1.40	1.19	0.17	0.16	0.17	0.16	5.1	4.0	5.3	4.5
Autumn	36	1.36	1.32	0.75	0.64	0.44	0.42	0.17	0.17	5.1	4.9	2.8	2.4
Annual	144	1.47	1.37	1.26	1.26	0.36	0.38	0.21	0.20	5.6	5.2	4.8	4.8

Table 2. Root mean square difference and standard deviation between observed values and estimated values using present history (old) and water mass history (new) in the Virginia Capes area

was estimated in an inversion using the water mass history first with and then without the adjustment routine and compared with observed values from 20 STD drops. Results of the evaluation -- given in Table 3 -- indicate that adjusted salinity values are clearly superior to unadjusted values in temperature inversions.

CONCLUSIONS AND RECOMMENDATIONS

The new water mass file offers substantial advantages over conventional oceanographic data files. The major advantage of the new file is the capability of the system to automatically discern in which of several possible water masses an input observation was taken, thus providing for variable water mass boundaries. An evaluation of the water mass selection capability showed that significantly better results were realized by its utilization. A second feature of the new file is salinity adjustment within a temperature inversion. A test of this capability showed that is provided a realistic estimate of salinity in an inversion. Finally, the quality control procedure to which the water mass file is subjected permits the use of large areas without loss of accuracy.

Several recommendations are warrented based on the evaluation of the water mass file:

A. The water mass file should be expanded to include the Indian and North Pacific Oceans.

B. That the water mass file replace the 5-degree history file presently used in ICAPS.

C. That the water mass file should be adopted as the navy-wide oceanographic history file for on-scene applications.

		SALINITY (°/oo)		SOUND SPEED (m/s)	
	N	RMS	SD	RMS	SD
Adjusted	57	0.58	0.49	0.8	0.7
Unadjusted	57	0.87	0.61	1.1	0.9

Table 3. Root mean square difference and standard deviation between observed and estimated values with and without salinity adjustment in temperature inversions

D. Salinity in the proposed file is determined as a function of water mass, season, and depth. In future water mass files it is recommended that salinity be determined as a function of water mass, temperature, depth, and season to take advantage of the unique thermohaline relationships which by definition, identify any given water mass using a technique similar to that used in the western North Atlantic Ocean by Fisher.

E. Because the effect of averaging masks real features, it is recommended that an ancillary file containing digitized XBT traces typical of each water mass on a monthly basis be constructed to provide users with information vital to realistic planning of future fleet operations.

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APPENDIX

SALINITY ADJUSTMENT

Oceanographic stability is a prime requisite for persistence of near-surface temperature inversions, for unstable conditions would destroy an inversion through mixing in a relatively short period. In physical oceanography, stability is quantified by the change in density with respect to change in depth; stable conditions being denoted by a positive gradient. Because density is a function of both temperature and salinity, it follows a priori that a salinity inversion must coincide with a temperature inversion if stability is to be maintained. Historical salinities, by definition, represent mean conditions and thus cannot cope with an anomalous condition such as an inversion. This appendix describes a method of adjusting salinity as estimated from an historical file to provide a stable water column. In order to allow for minor instabilities frequently in Arctic waters, the correction is only applied where a temperature inversion exceeds 0.25°C.

The equation used to adjust historical salinity was derived from stepwise regression of density as a function of salinity (30 to 40 °/oo) and constant temperature (10°C)

$$\rho = -1.26584\times10^{-1}+7.72412\times10^{-1}S+4.22003\times10^{-8}S^{4} \qquad (1)$$

Differentiation of equation (1) to give change of density with respect to change in salinity yields, after rearrangement, addition of a correction term to assure stability within the inversion, and conversion of density to the more conventional sigma-t yields

$$\Delta S_i = \frac{\Delta\sigma_t - C_i}{0.7724+1.6880\text{x}10^{-7}S_o^{\,3}} \tag{2}$$

Where $\Delta\sigma_t$: the difference between σ_t at adjacent points,

C_i : the corrective term, and

S_o : original historical salinity at point i

The initial step in applying equation (2) is the computation of sigma-t as a function of depth and temperature as input from the XBT and interpolated historical salinity. The XBT is scanned from bottom to top and salinity values adjusted for all points within temperature inversions that are more than 0.25°C less than the temperature maximum at the lower boundary of the inversion. The corrective term is increased by 0.01 sigma-t units per depth increment to assure stability within the inversion. Adjusted historical salinity (S_i) is now computed using the equation

$$S_i = S_o + \Delta S_i \tag{3}$$