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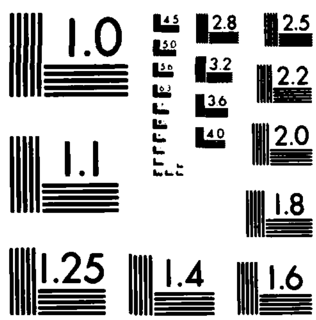

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DETERMINATION OF STABILITY FROM TEMPERATURE PROFILES

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Robert J. Wahl

Physical Oceanography Branch

OCEAN MEASUREMENTS PROGRAM

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FOREWORD

This report explores the feasability of deriving profiles of Brunt-Vaisala frequency from measured temperature profiles and regional temperature-salinity relationships. Detailed knowledge of the Brunt-Vaisala frequency, which is the controlling factor for internal waves, is critical in addressing Ocean Measurements Program requirements for characterizing the upper ocean environment. Analyses utilizing the techniques described herein for deriving Brunt-Vaisala frequency from XBT temperature profiles will be performed for areas of principal interest to the Ocean Measurements Program.

C. H. BASSETT
Captain, USN
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Brunt-Vaisala Frequency, XBT, Temperature Profiles, T-S Diagrams, CTD, Vertical Stability, Sargasso Sea, Northeast Atlantic

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Vertical profiles of Brunt-Vaisala (BV) frequency derived from measured temperature and constructed salinity data were compared to BV frequency profiles calculated from CTD data. The salinity profiles were constructed using averaged CTD or historical data from relatively quiet and active areas. The methods used in deriving salinity are based on: an averaged temperature-salinity relationship, pressure averaged salinity, and constant salinity profiles. The quality of the derived BV frequency was found to depend on the method used and amount of local variability.

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INTRODUCTION

An important measure describing the structure of the ocean is its vertical stability as expressed by the Brunt-Vaisala frequency (N) profile. The derivation of these profiles requires a knowledge of the vertical density profile which is calculated from temperature and salinity measurements. If expendable bathythermograph (XBT) temperature measurements could be used in combination with historical data to estimate Brunt-Vaisala frequency profiles, a better description of the water structure on shorter time scales or over larger areas would be obtained.

A similar situation is encountered in the computation of dynamic topographies from temperature data. Emery (1975) showed that in regions dominated by a single water mass, or in regions with very similar Temperature-Salinity (T-S) relationships, dynamic heights can be estimated from XBT temperature profiles using salinity values derived from average T-S relationships. Wyrtki (1978) derived dynamic topographies directly from average temperature-density relationships and XBT data, since temperature-density curves have the advantage of being smoother than corresponding T-S curves. Emery and O'Brien (1978) have shown that in regions of multiple-valued T-S relationships salinity can be more accurately inferred for the computation of dynamic heights from mean salinity-depth curves.

In this study several approaches for estimating vertical stability of the water column from temperature profiles and averaged in situ or historical salinity data are examined. Some of these approaches are similar to those used for the computation of dynamic heights with XBT data.

METHODS

Estimates of Brunt-Vaisala frequencies were calculated from CTD (Conductivity, Temperature, and Depth) temperature data and corresponding salinities inferred from averaged in situ CTD measurements or historical data. These estimated Brunt-Vaisala frequencies were then compared to Brunt-Vaisala frequencies calculated directly from the in situ CTD measurements.

Salinity profiles were inferred using three methods: average temperature and salinity relations (average T-S method), average salinity-depth profiles (average S-Z method), and constant salinity profiles (CS method). All three methods were evaluated with data from 31 CTD stations in the Sargasso Sea and 12 CTD stations in the Iceland-Faeroe frontal area (figure 1). The CTD data consisted of data at one-meter vertically-spaced intervals, low-pass filtered with a half-power point at 10 meters. In addition, data from the Naval Oceanographic Office Generalized Digital Environmental Model (GDEM) (Colborn, Daubin, Hashimoto, and Ryan, 1980) for the Sargasso Sea were also :ilized ' the average T-S method.

In the average T-S method Brunt-Vaisala frequencies are estimated from in situ CTD temperature measurements and salinity values inferred from an average T-S relationship. Average T-S relationships are derived from in situ temperature and salinity station data ensemble averaged at one-meter depth intervals and also from GDEM temperature and salinity profiles at standard National Oceanographic Data Center (NODC) depths. The GDEM data are based on historical temperature and salinity profiles and were obtained for a 30 by 30 minute quadrant on a seasonal basis.

In the average S-Z method, Brunt-Vaisala frequencies are estimated using temperatures from an in situ CTD temperature profile and corresponding salinities from an average salinity profile. The average salinity profiles are formed by ensemble averaging individual salinity profiles at one-meter depth intervals.

Finally, in the CS method, Brunt-Vaisala frequencies are estimated from in situ CTD temperature measurements and a constant salinity. The constant salinity value must be representative for the area.

DISCUSSION

A. AVERAGE T-S METHOD

A prerequisite for accurate results in the use of the average T-S method is a "tight" and "smooth" T-S envelope. In a tight T-S envelope, the standard deviation in salinity is less than 0.1 ppt

(Emery, 1975). In a smooth T-S envelope derivatives of the individual T-S curves are continuous.

CTD data from the 31 stations from the Sargasso Sea (Broome, Hallock, Karpas, Mulher, and Teague, 1980) present a tight and smooth T-S envelope at depths greater than 200 meters (figure 2). High variability of temperature and salinity is found in the upper 200 meters. The single anamolous T-S curve is associated with an eddy reported by Hallock, Teague, and Broome (1981).

Estimates of N to a depth of 1000 meters were calculated for a representative station from the Sargasso Sea data and were compared to N calculated from in situ temperature and salinities (figures 3-5). Overall agreement between estimated and in situ Brunt-Vaisala frequencies were found in areas of reliable salinity estimates or where temperature dominated density. Less reliable salinity estimates were found at temperature inversions and thermocline transitions.

In regions with high mesoscale variability in the temperature and salinity structures, as encountered south of the Iceland-Faeroe front (Teague, 1981), the T-S envelope may be tight, but not smooth (figure 6). Salinity estimates from the average T-S method are unreliable and result in poor agreement between the estimated and in situ Brunt-Vaisala frequency profiles (figure 7).

B. AVERAGE S-Z METHOD

The average S-Z method provides good estimates of N where the envelope of the in situ salinity profiles is tight, i.e. the standard deviation of salinity is less than .01 ppt. An envelope formed by two salinity profiles from the Iceland-Faeroe frontal area illustrates tightness below 300 meters (figure 8). For these profiles good agreement between N and the estimates of N were found in the surface layer where density is dominated by temperature, and below 300 meters where good salinity estimates were found with the average S-Z method (figures 9 and 10). Poor salinity estimates, associated with positive temperature gradients between 70 and 300 meters, produced errors on the order to 2 cph in estimating Brunt-Vaisala frequencies. Better estimates of salinity and Brunt-Vaisala frequency were obtained with the average S-Z method (figure 8) than from the average T-S method (figure 11) in depth ranges associated with multiple-valued average T-S curves (figure 12).

C. CS METHOD

Constant salinity can be a viable method for the determination of Brunt-Vaisala frequencies under strict conditions: small salinity gradients in the absence of temperature inversions (figure 13), or strong temperature gradients (figure 14). Compensating T-S structures result in poor approximations of Brunt-Vaisala frequencies such as are evident, for example, near the base of the mixed layer shown in figure 15. The presence of a salinity gradient error will cause an offset in estimating Brunt-Vaisala frequencies (figure 16).

D. MODEL AVERAGE T-S METHOD

Environmental model data may be a useful resource for obtaining an average T-S curve for the computation of Brunt-Vaisala frequencies in areas where in situ salinity data are not available. Temperature and salinity profiles were extracted from GDEM at locations closely corresponding to the locations of the stations shown in figure 2. The effect of long-term averaging, not evident in the in situ CTD data, is evident in the broader model T-S envelope below the 18 degree isotherm (figure 17). The coarser vertically spaced seasonal averaged GDEM data also yielded a smoother average T-S curve than obtained from in situ data.

Reliable estimates of Brunt-Vaisala frequencies from the model average T-S method were found in the upper 200 meters (figure 18). Between 200 and 500 meters errors in the estimates of Brunt-Vaisala frequencies approached the magnitude of in situ Brunt-Vaisala frequencies, especially in the vicinity of poor salinity estimates and temperature inversions (figure 19). Poor salinity estimates in regions of highly variable T-S structure arise from long-term averaging. Although the in situ T-S curve falls within the bounds of the model T-S envelope, the in situ T-S curve possesses a different slope from the model average T-S curve between 500 and 1000 meters (figure 20). As a consequence the estimates of Brunt-Vaisala frequencies are underestimated where the slope of the estimated T-S relationship is less than the in situ slope and overestimated where the estimated slope is greater than the in situ slope.

COMPARISON OF METHODS

A comparison of the four methods is made using data from the Sargasso Sea in an area exhibiting "tight" and "smooth" T-S relationships. The mean Brunt-Vaisala frequency, mean error, and standard deviation profiles were computed using the data collected at the 31 CTD stations in the Sargasso Sea. Results are presented for each method in figures (21-24). Mean N, mean error, and standard deviation were filtered prior to plotting to suppress wavelengths less than 10 meters for a clearer presentation.

As expected, the average T-S method produced the best estimates of N for the Sargasso Sea data followed by model average T-S, average S-Z and CS methods. The largest mean error and standard deviation for all methods were found near the surface (about 1 cph mean error and 1-2 cph standard deviation), where N is largest (max N of approximately 13 cph), and near the top of the main thermocline between 450 and 600 meters (about .5 cph mean error and 1 cph standard deviation). The mean errors for all methods were similar between 100 and 450 meters (0.0-0.2 cph); standard deviation ranged from 0.2 cph (average T-S method) to 0.4 cph (average S-Z method). Below 600 meters, the mean error ranged from 0.2 cph (average T-S method) to 1.2 cph (average S-Z); the standard deviation ranged from 0.2 cph (average T-S method) to 1.0 cph (CS Method).

SUMMARY AND CONCLUSION

Various methods for estimating Brunt-Vaisala frequency profiles from in situ temperature and inferred salinity have been examined. Most accurate derivations of Brunt-Vaisala frequency profiles are found when in situ salinity data are used in the methods. In many circumstances, when in situ salinity data are not available, model data may be a useful alternative. Estimates of N by all of the above methods examined in this paper are acceptable under certain conditions. All methods presented have problems with temperature inversions and thermocline transition zones. Good estimates of N by each method were found in regions of temperature dominated density gradients.

The selection of an appropriate method of estimating Brunt-Vaisala frequencies from XBT temperature profiles is based on the T-S structure encountered in the area. If the T-S envelope is "tight" and "smooth" the average T-S method yields good estimates of Brunt-Vaisala frequencies. Areas characterized by tight, non-smooth T-S envelopes may exhibit tight, structured envelopes of salinity profiles. For these areas the average S-Z method will give good estimates of N. The derivation of the average T-S curves from model data results in a smoother curve than a curve based on synoptic salinity temperature observations. Using model data instead of in situ data for obtaining T-S relationships may result in greater uncertainties in estimating Brunt-Vaisala frequencies. These uncertainties arise from long-term averaging, highly variable spatial interpolation, and low vertical resolution. For areas characterized by negligible salinity gradients, the constant salinity method will yield good estimates of Brunt-Vaisala frequencies; a selection of a nonrepresentative salinity value will bias the estimates of Brunt-Vaisala frequencies.

The choice of the method for determining Brunt-Vaisala frequencies depends upon the salinity structure characteristic of the area, and ultimately on the available salinity data. In some regions, a combination of methods may result in best estimates of Brunt-Vaisala frequencies.

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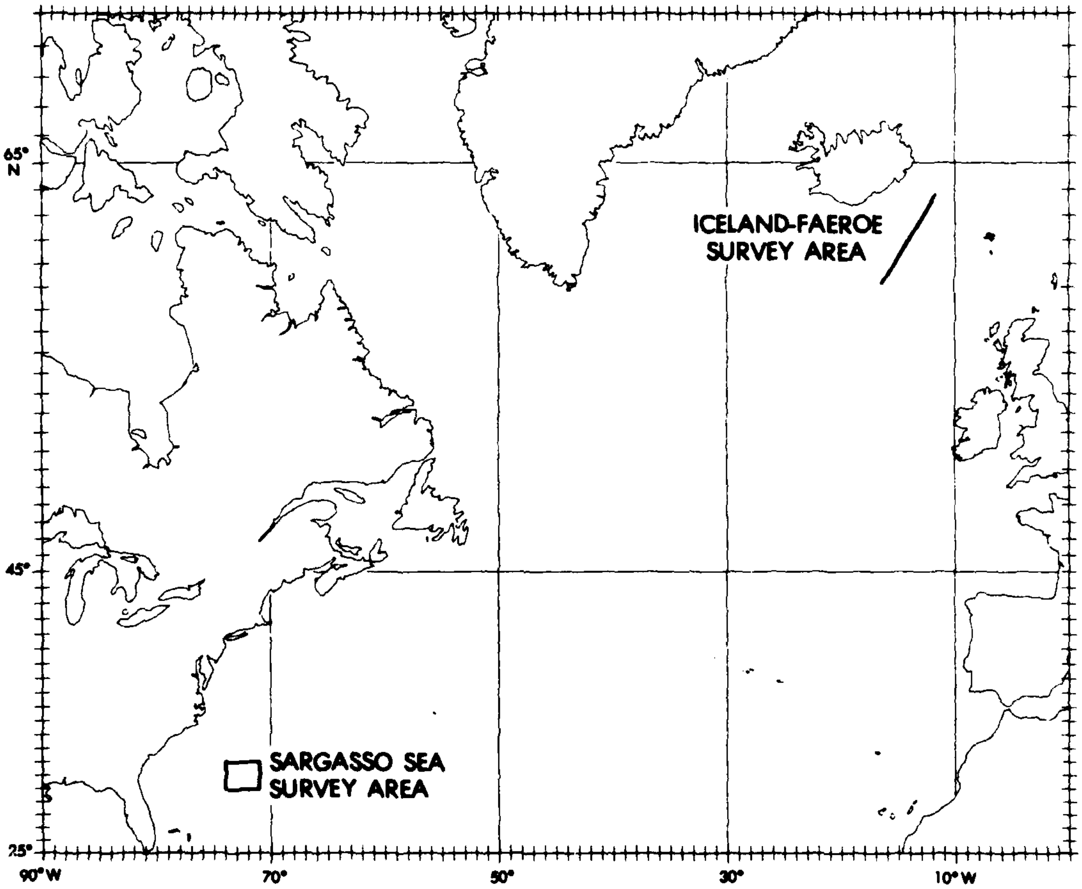

Figure 1 CTD survey locations

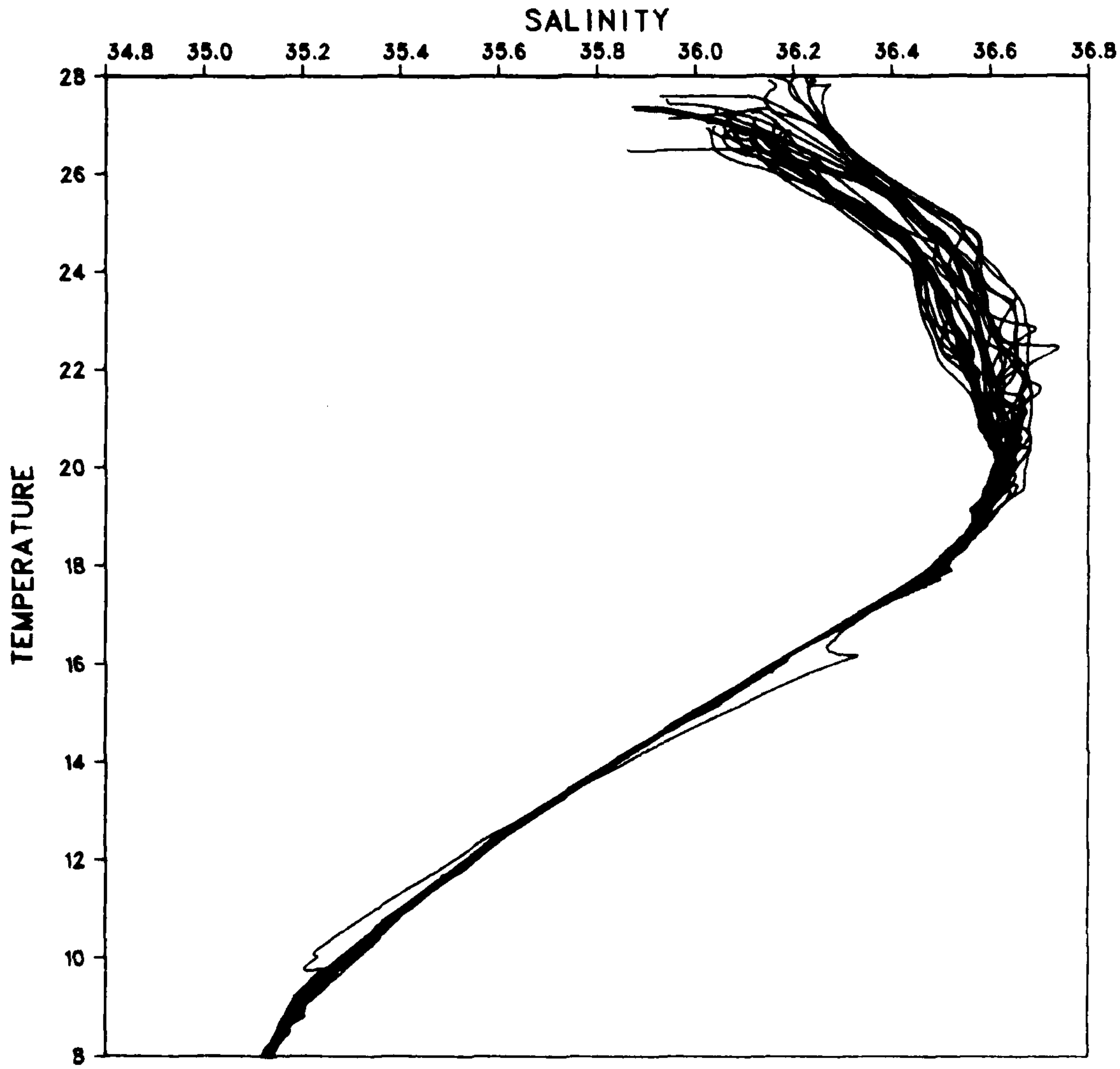

Figure 2 T-S envelope consisting of 31 CTD stations from the Sargasso Sea

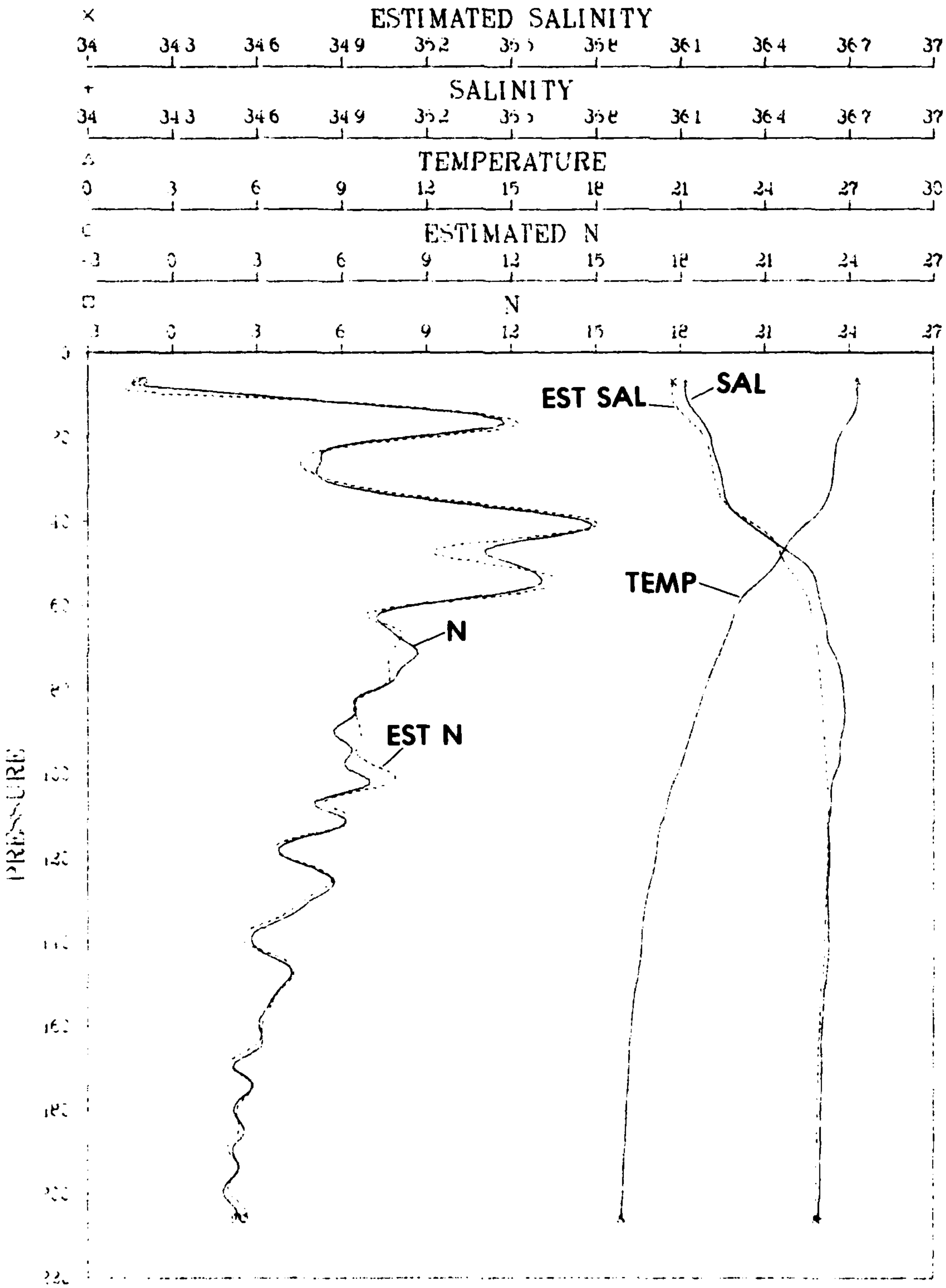

Figure 3 Average T-S method applied to cast 7 from the Sargasso Sea between 0 and 200 meters for 31-station average

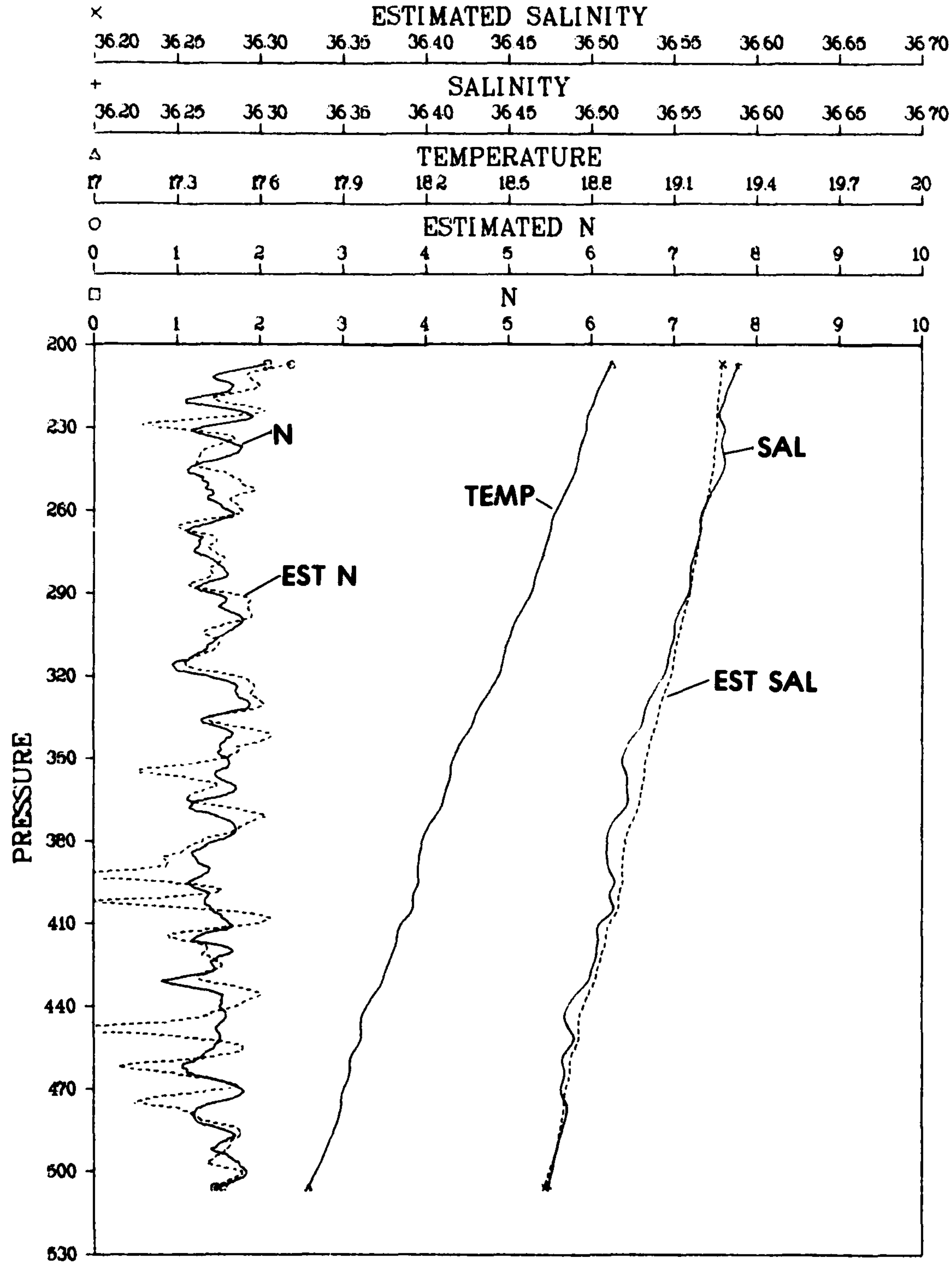

Figure 4 Average T-S method applied to cast 7 from the Sargasso Sea between 200 and 500 meters for 31-station average

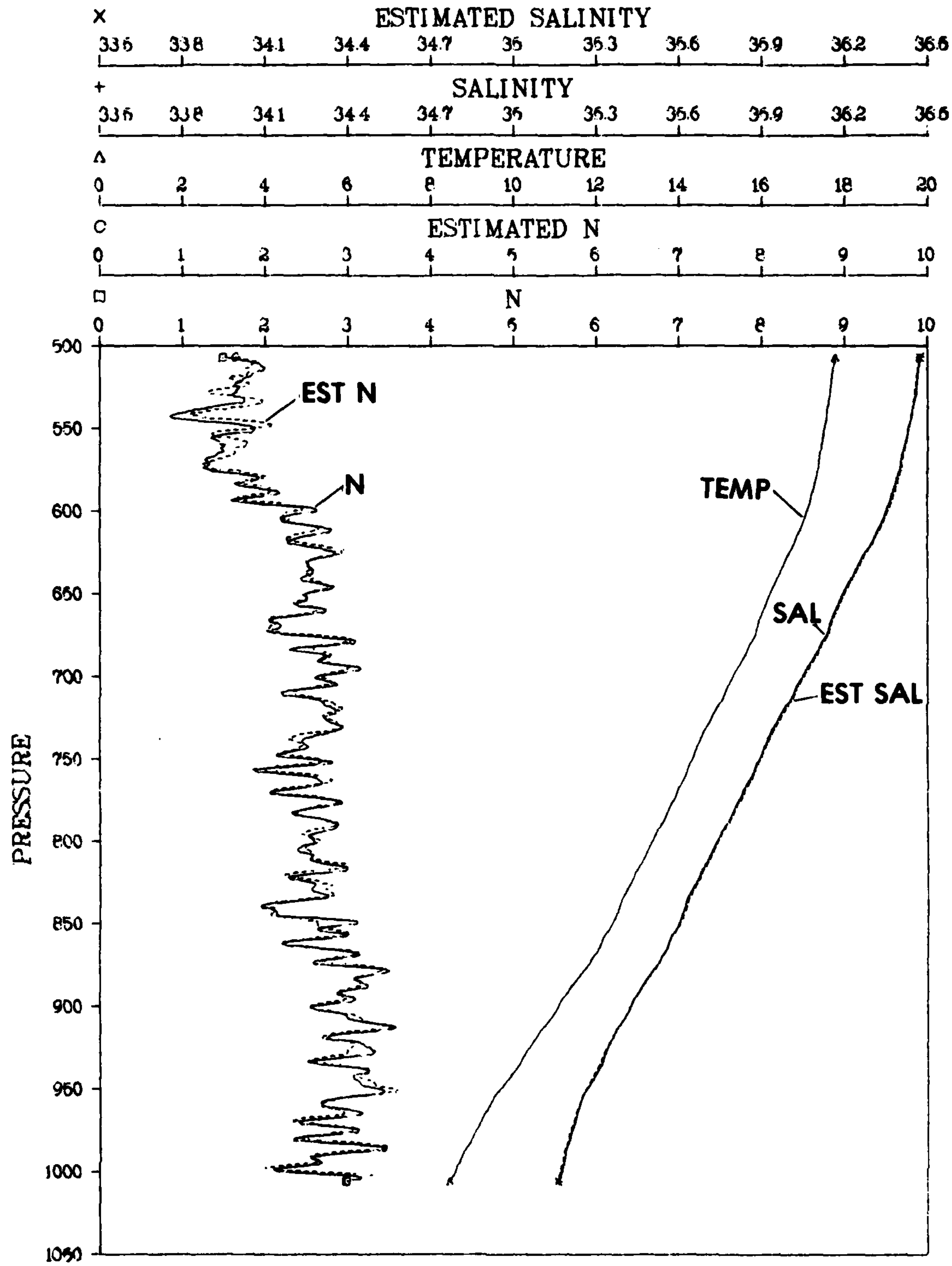

Figure 5 Average T-S method applied to cast 7 from the Sargasso Sea between 500 and 1000 meters for 31-station average

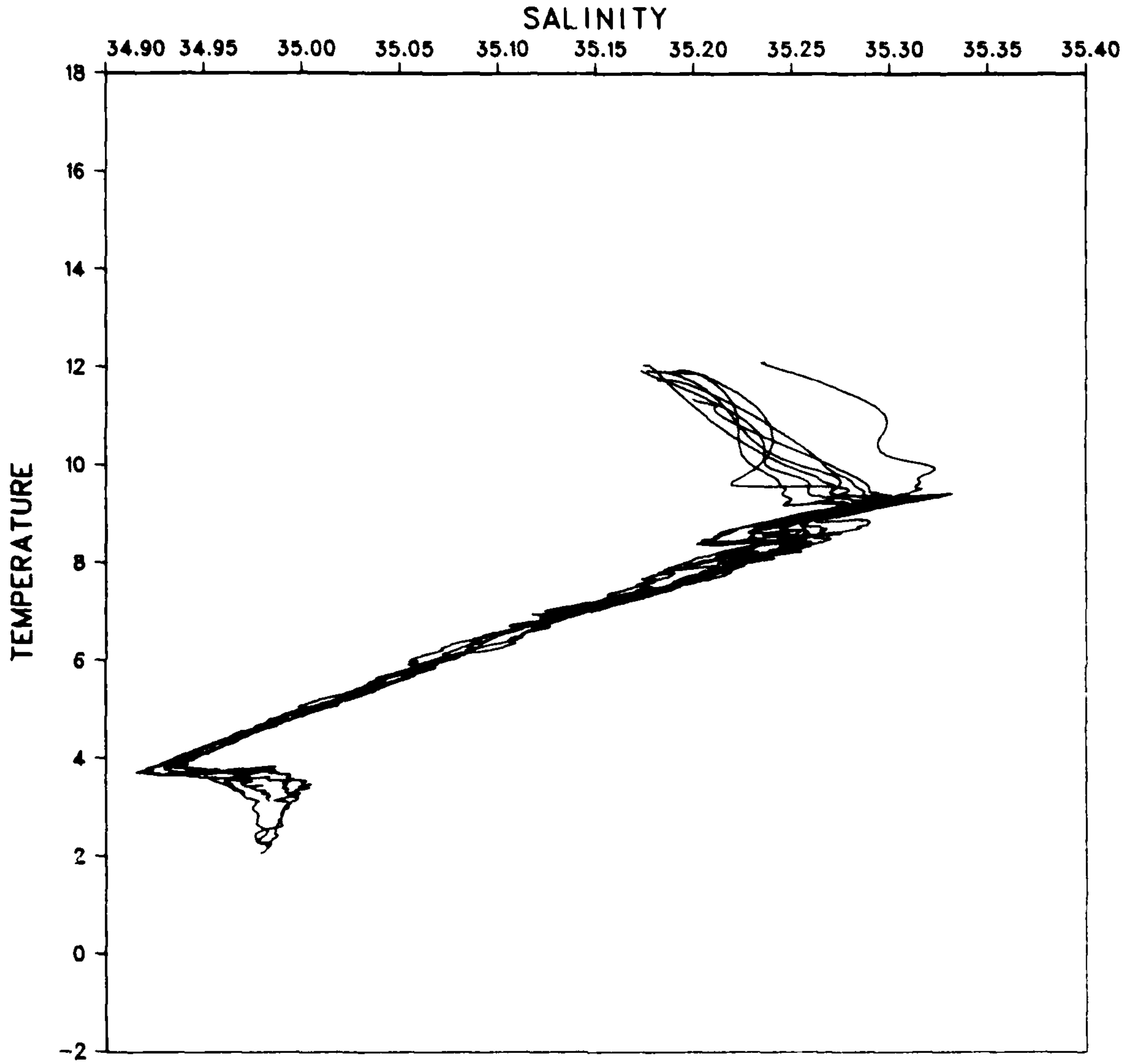

Figure 6 T-S envelope consisting of 8 CTD stations from the Iceland-Faeroe frontal area

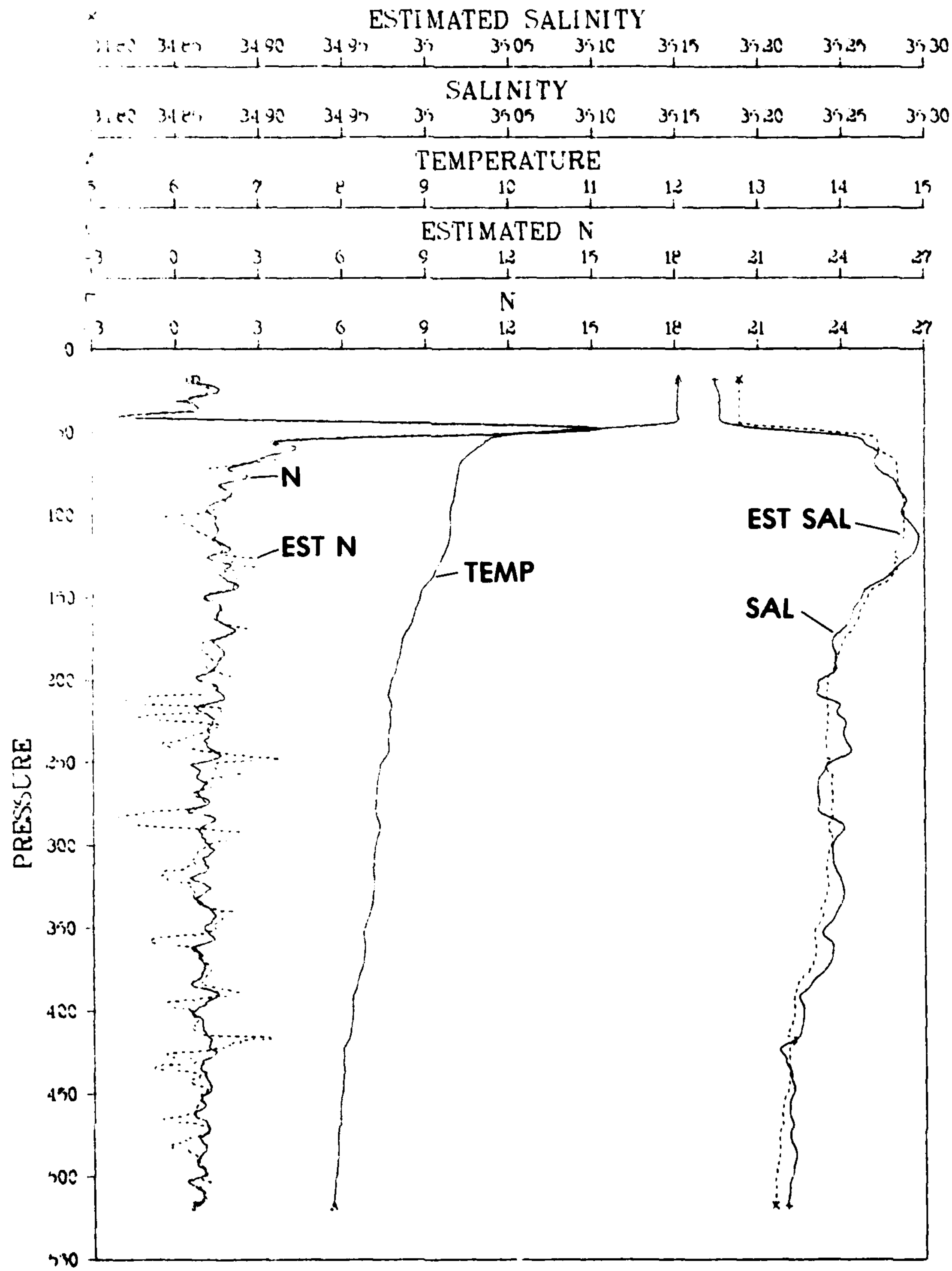

Figure 7 Average T-S method applied to cast 14 from the Iceland-Faeroe frontal area between 0 and 500 meters for 8-station average

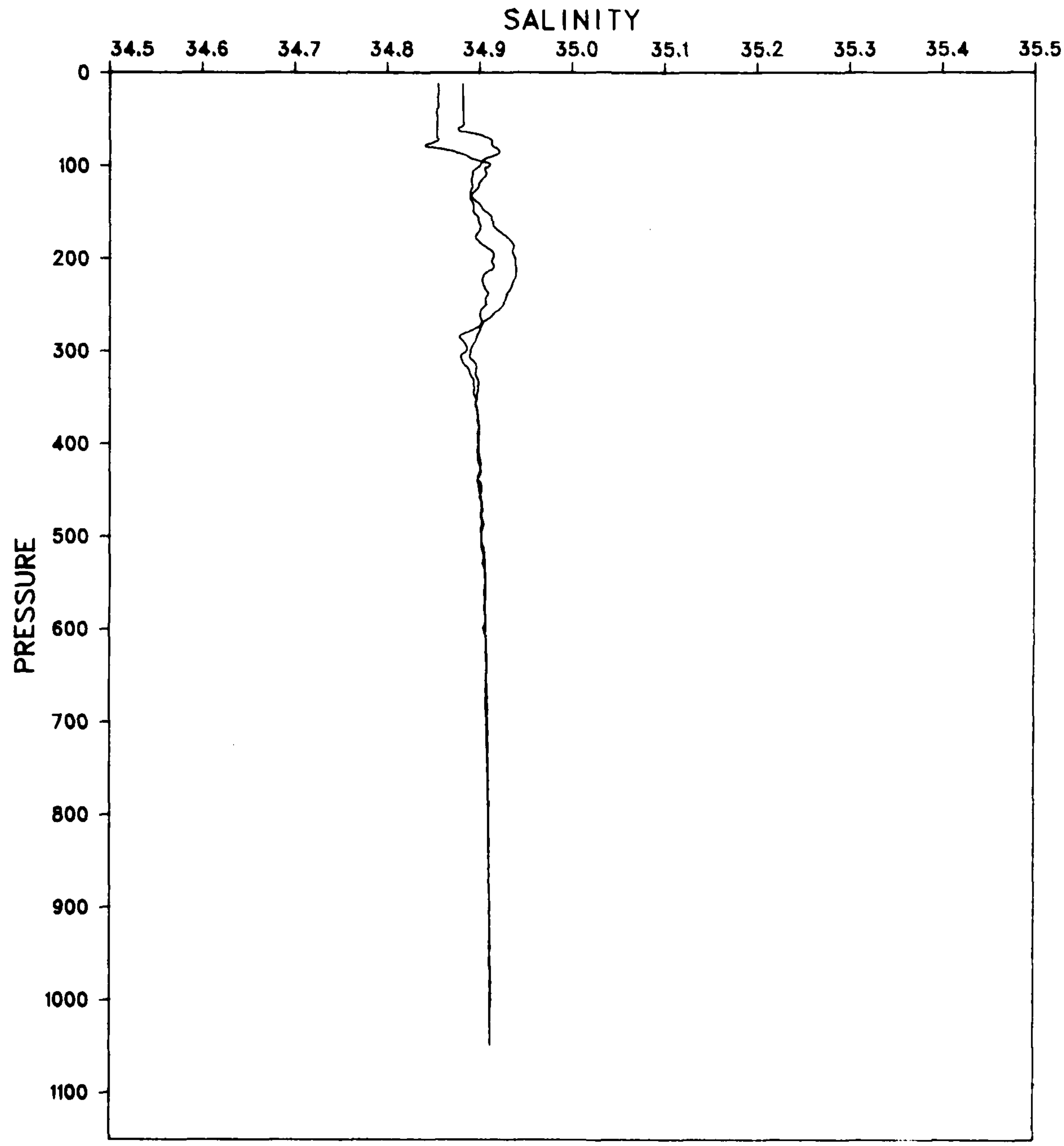

Figure 8 Salinity profiles for 2 stations from the Iceland-Faeroe frontal area

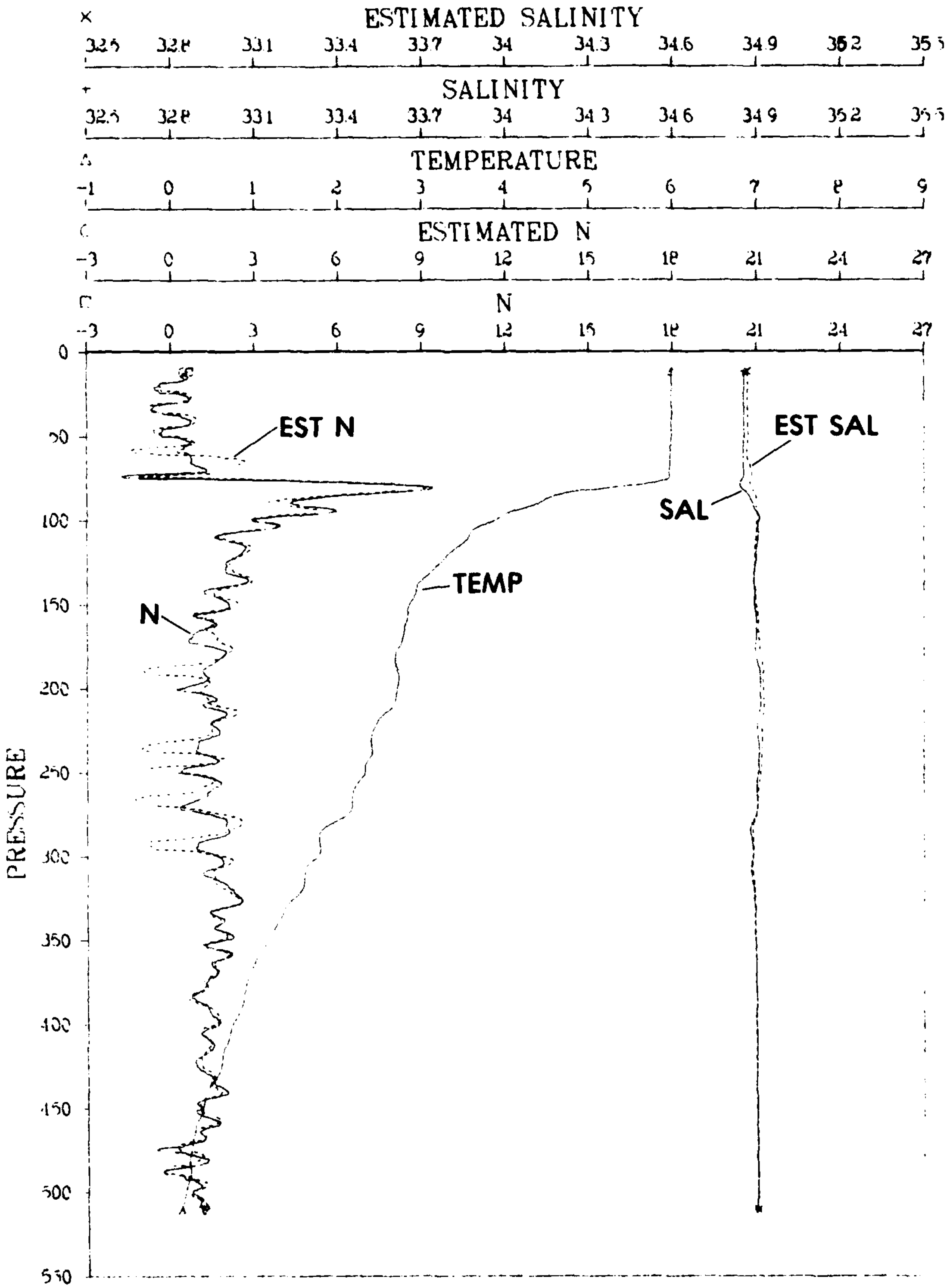

Figure 9 Average Salinity method applied to cast 100 from the Iceland-Faeroe frontal area between 0 and 500 meters for 2-station average

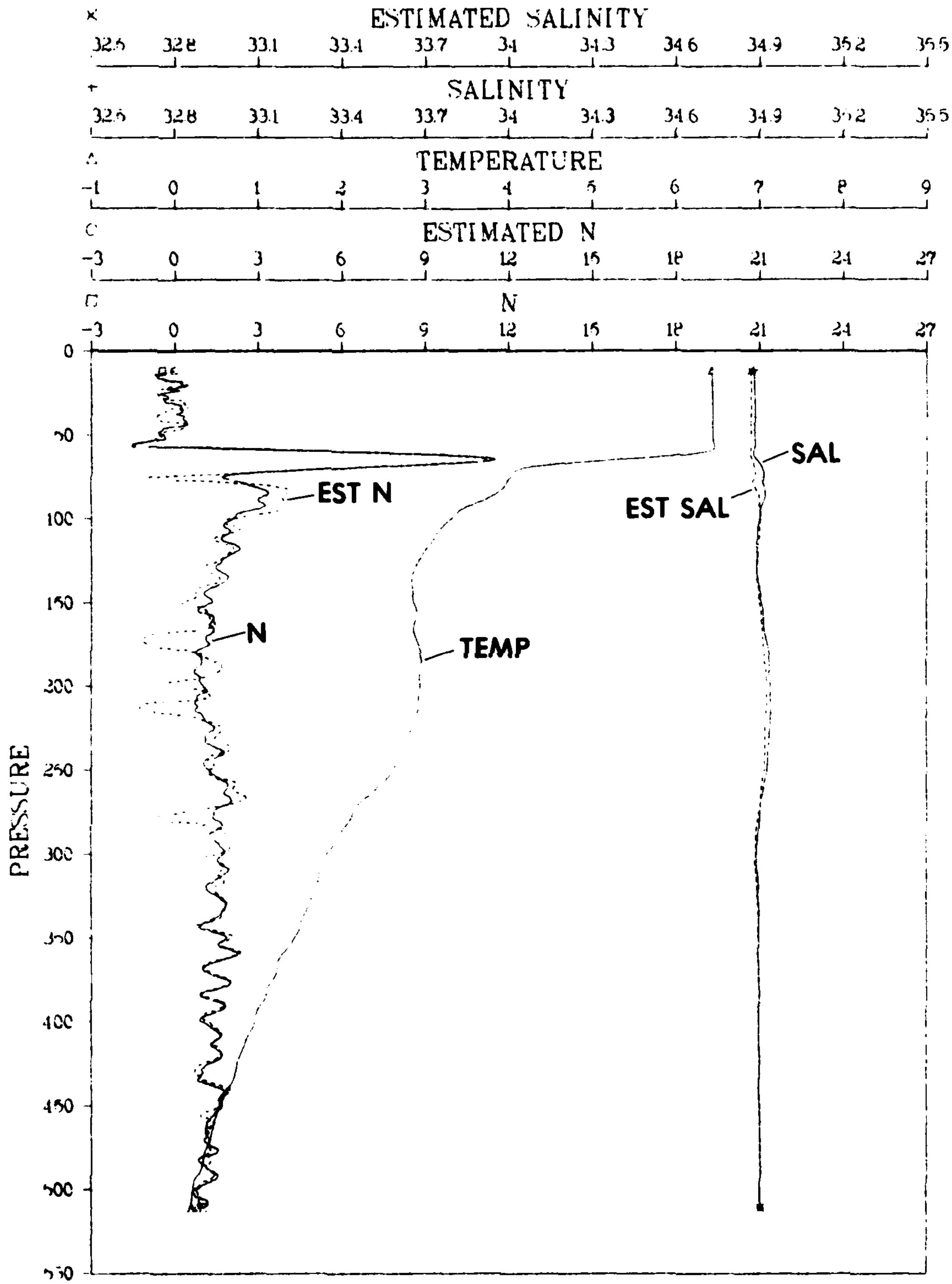

Figure 10 Average Salinity method applied to cast 101 from the Iceland-Faeroe frontal area between 0 and 500 meters for 2-station average

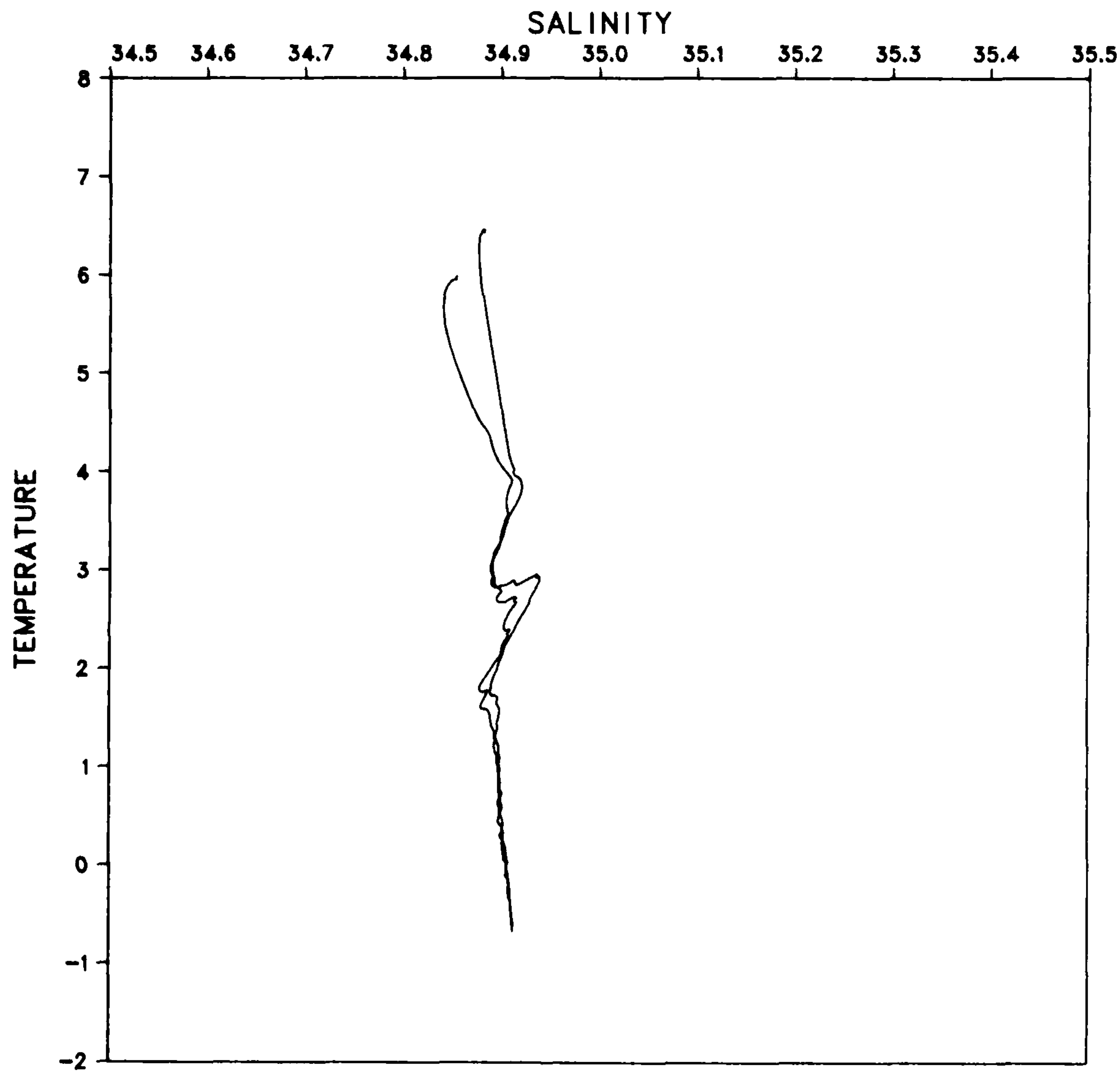

Figure 11 T-S envelope consisting of 2 CTD stations from the Iceland-Faeroe frontal area

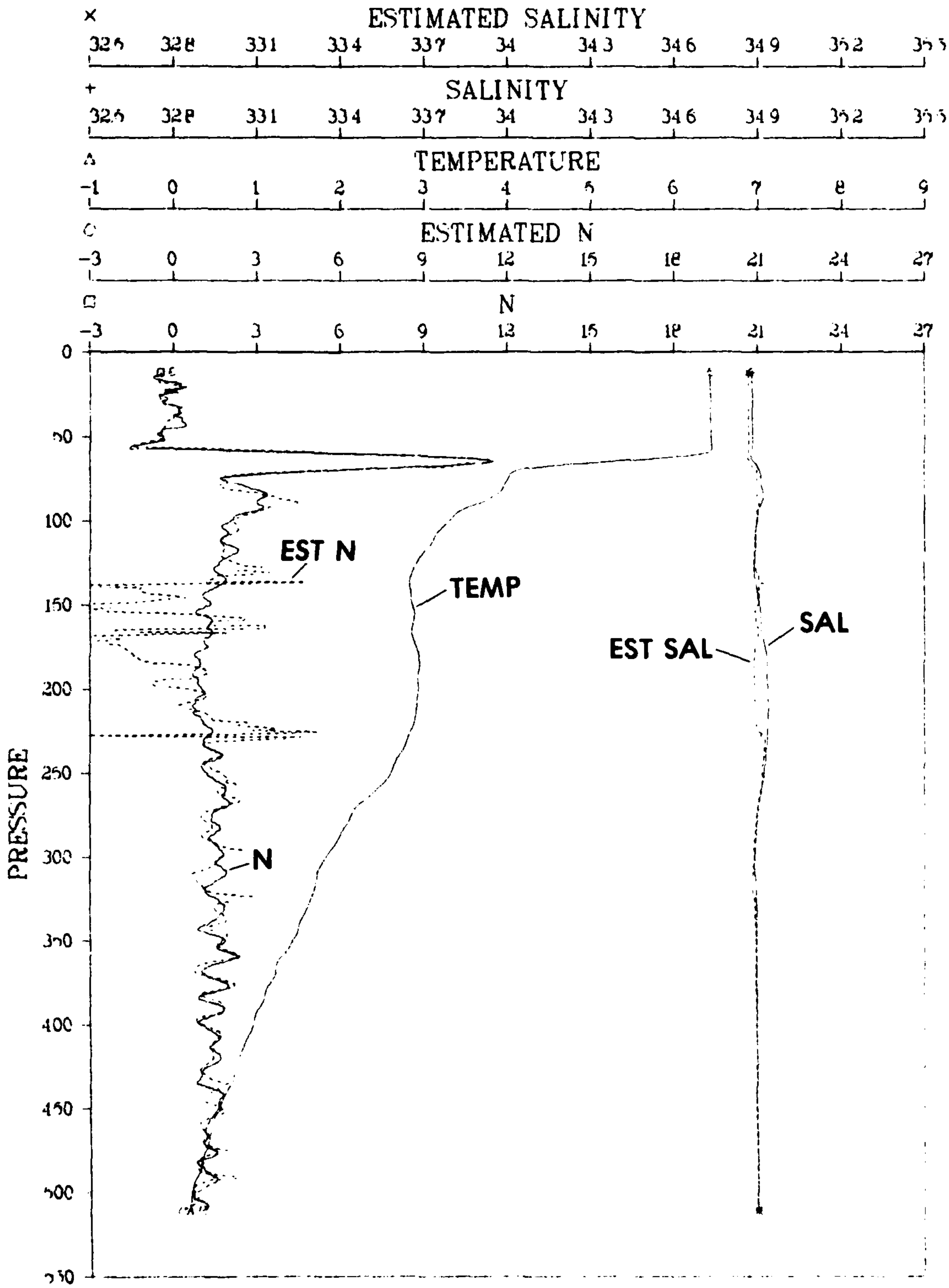

Figure 12 Average T-S method applied to cast 101 from the Iceland-Faeroe frontal area between 0 and 500 meters for 2-station average

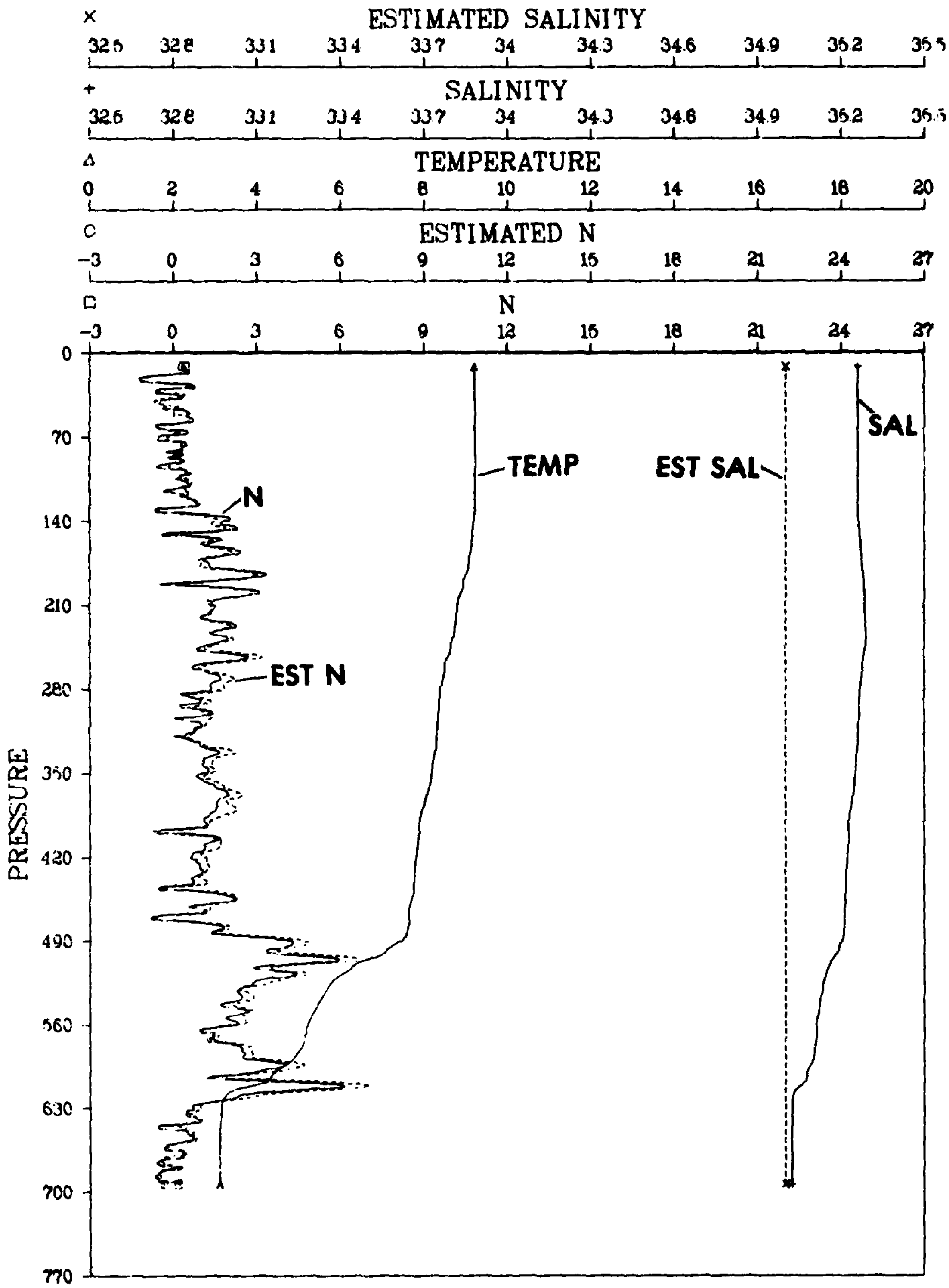

Figure 13 Constant Salinity method applied to cast 84 from the Iceland-Faeroe frontal area between 0 and 700 meters

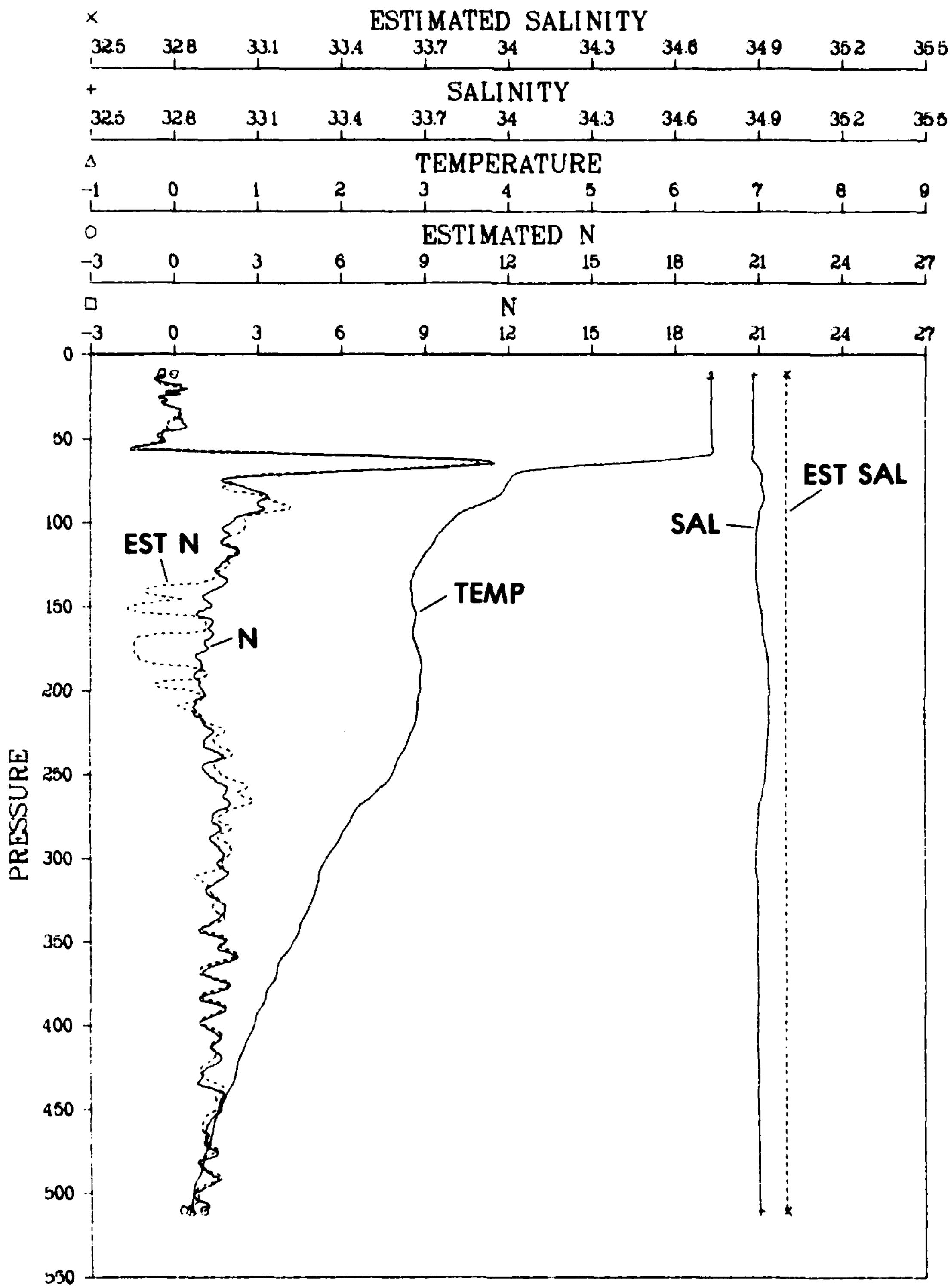

Figure 14 Constant Salinity method applied to cast 101 from the Iceland-Faeroe frontal area between 0 and 500 meters

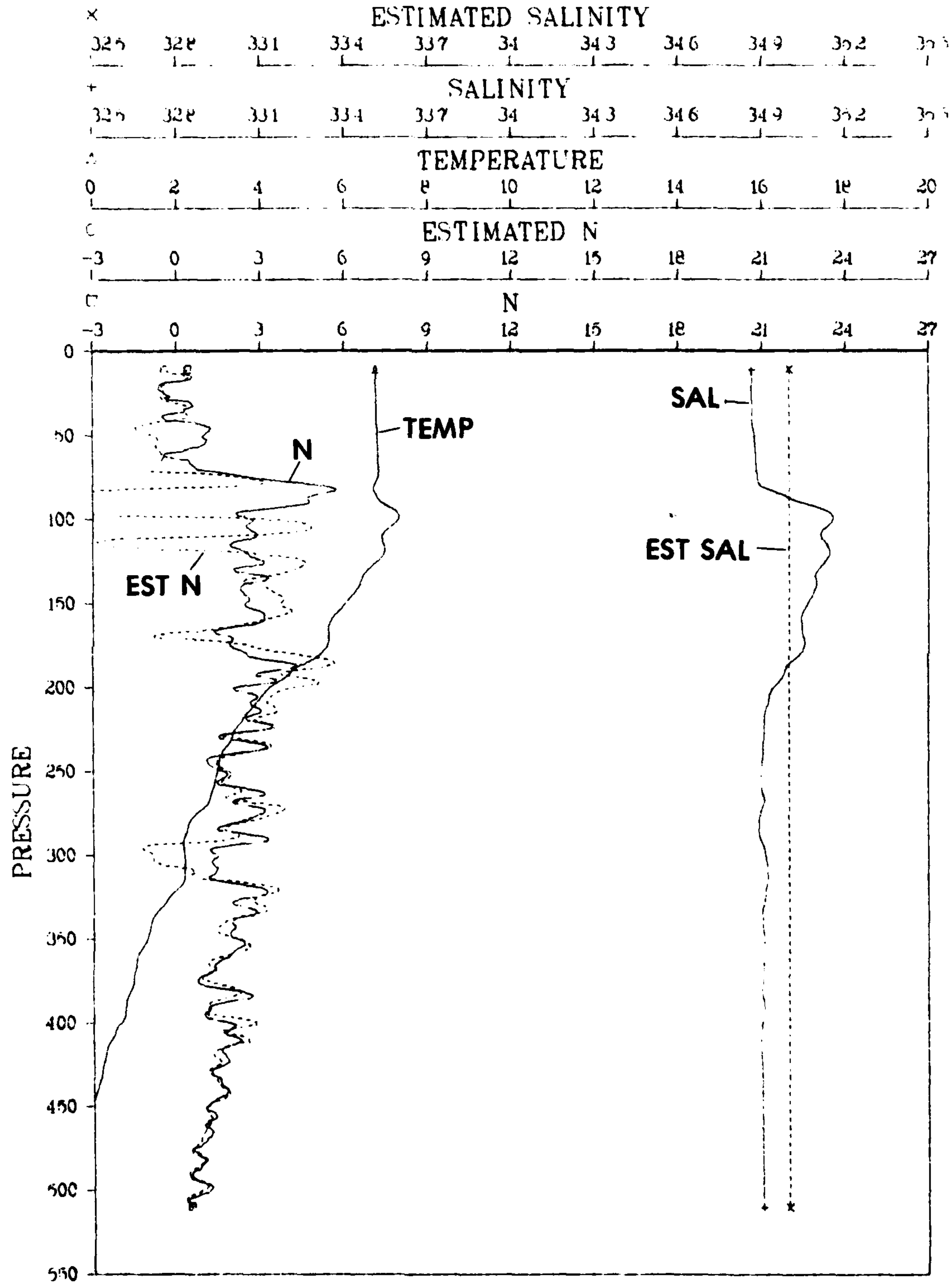

Figure 15 Constant Salinity method applied to cast 89 from the Iceland-Faeroe area between 0 and 500 meters

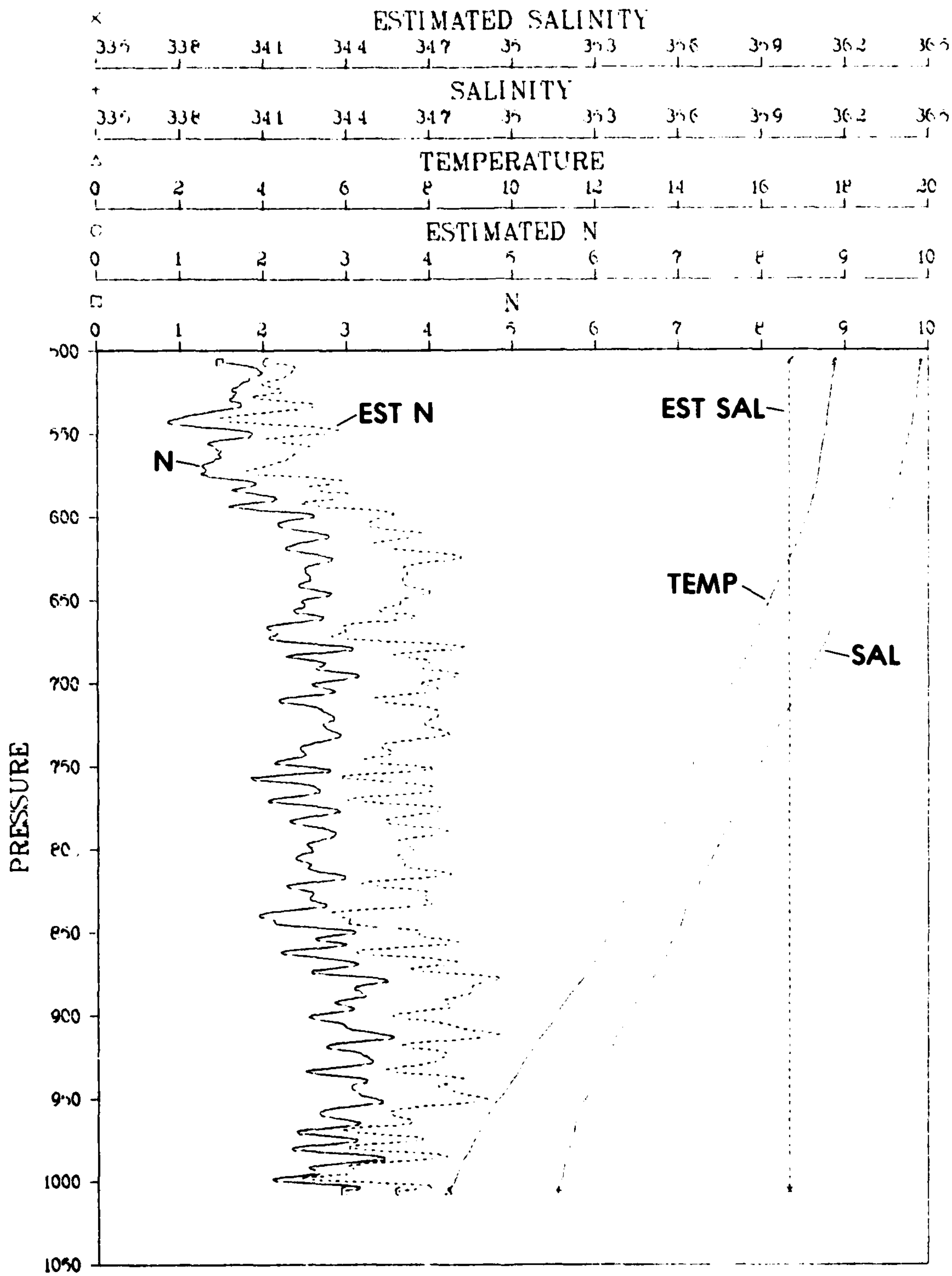

Figure 16 Constant Salinity method applied to cast 7 from the Sargasso Sea between 500 and 1000 meters

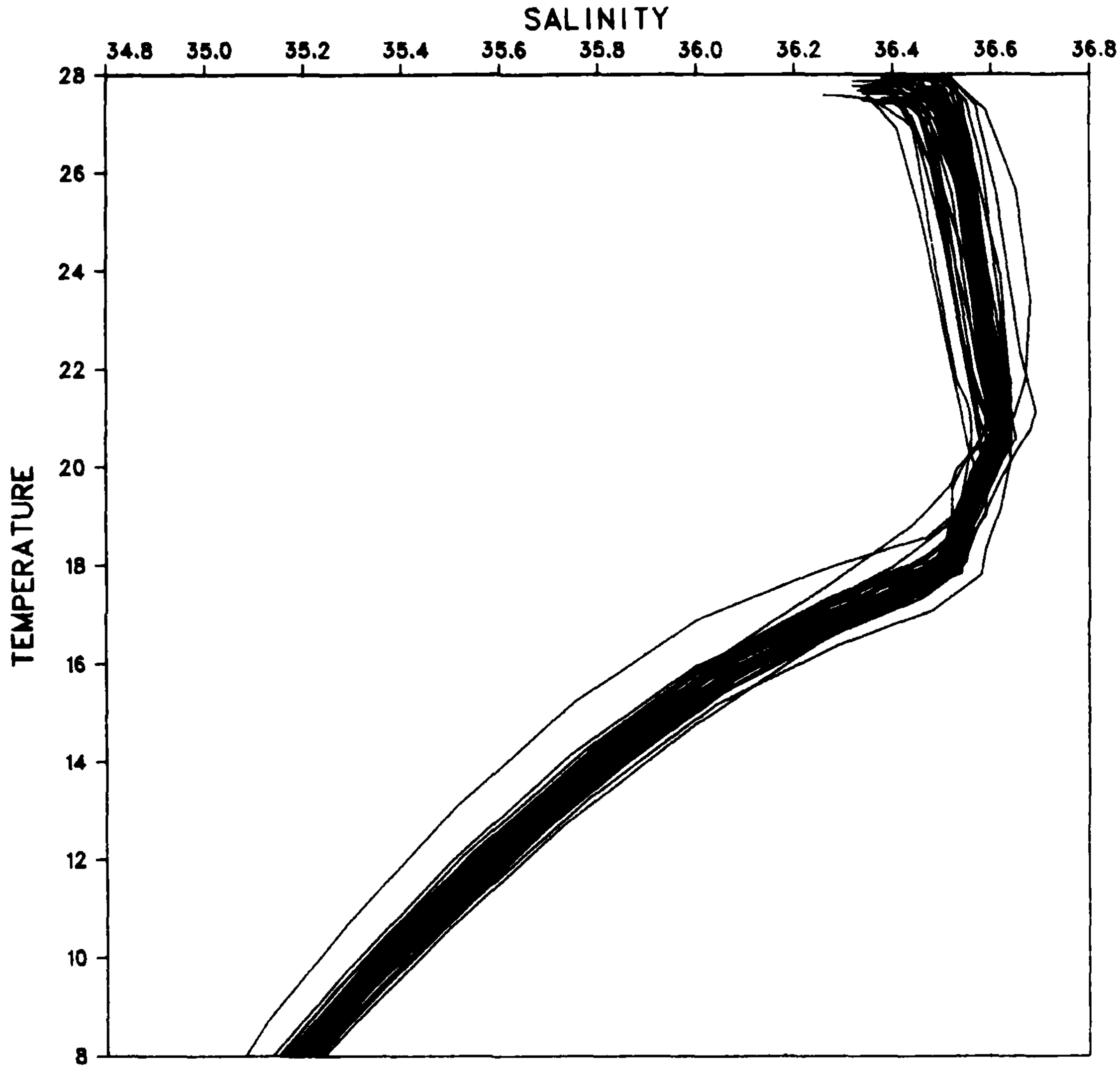

Figure 17 T-S envelope consisting of 35 T-S relationships from the Digital Environmental Model for the summer season between 30°-32°N, 71°-74°W

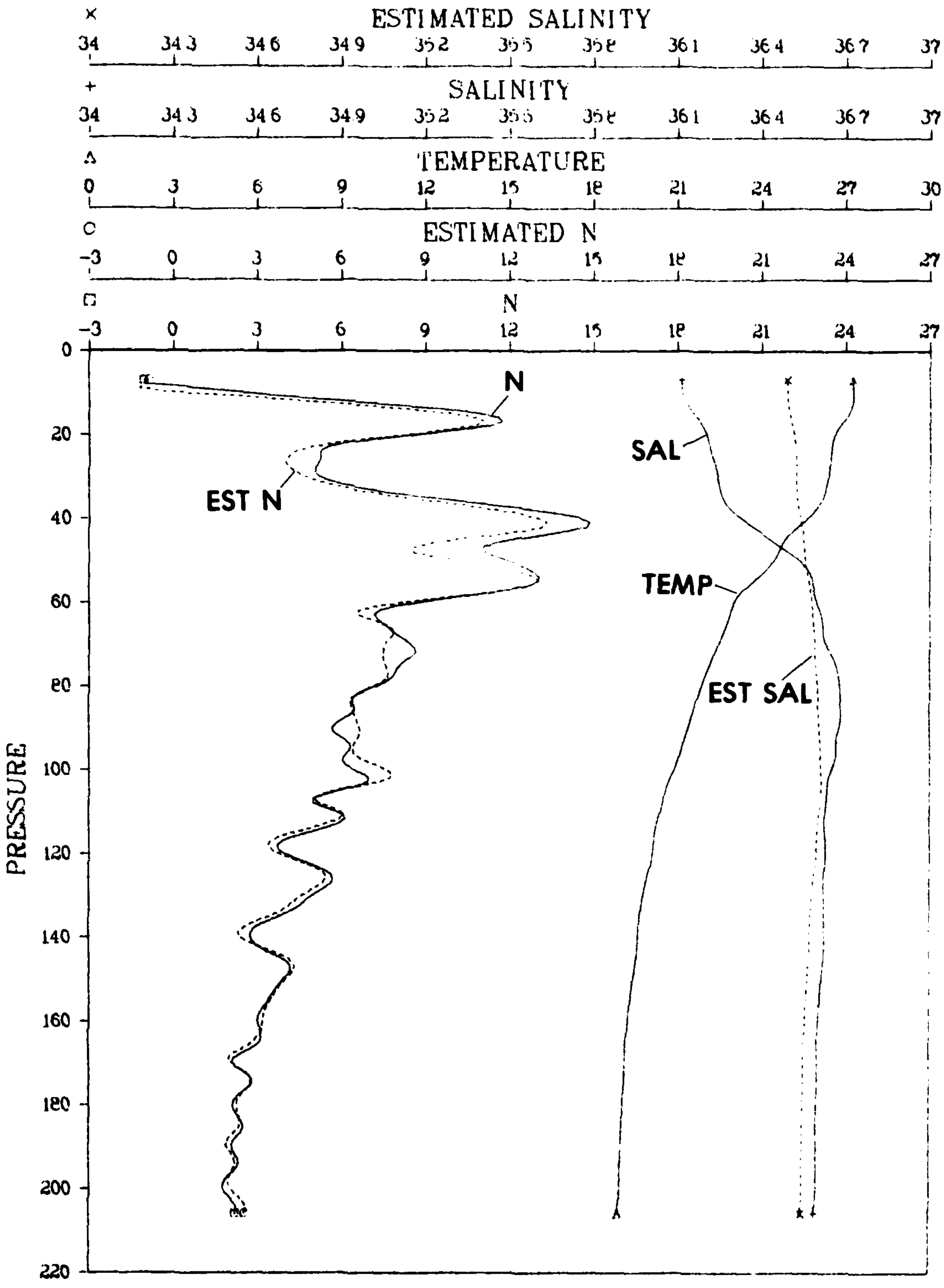

Figure 18 Average T-S method applied to cast 7 from the Sargasso Sea between 0 and 200 meters for 35 model averaged profiles

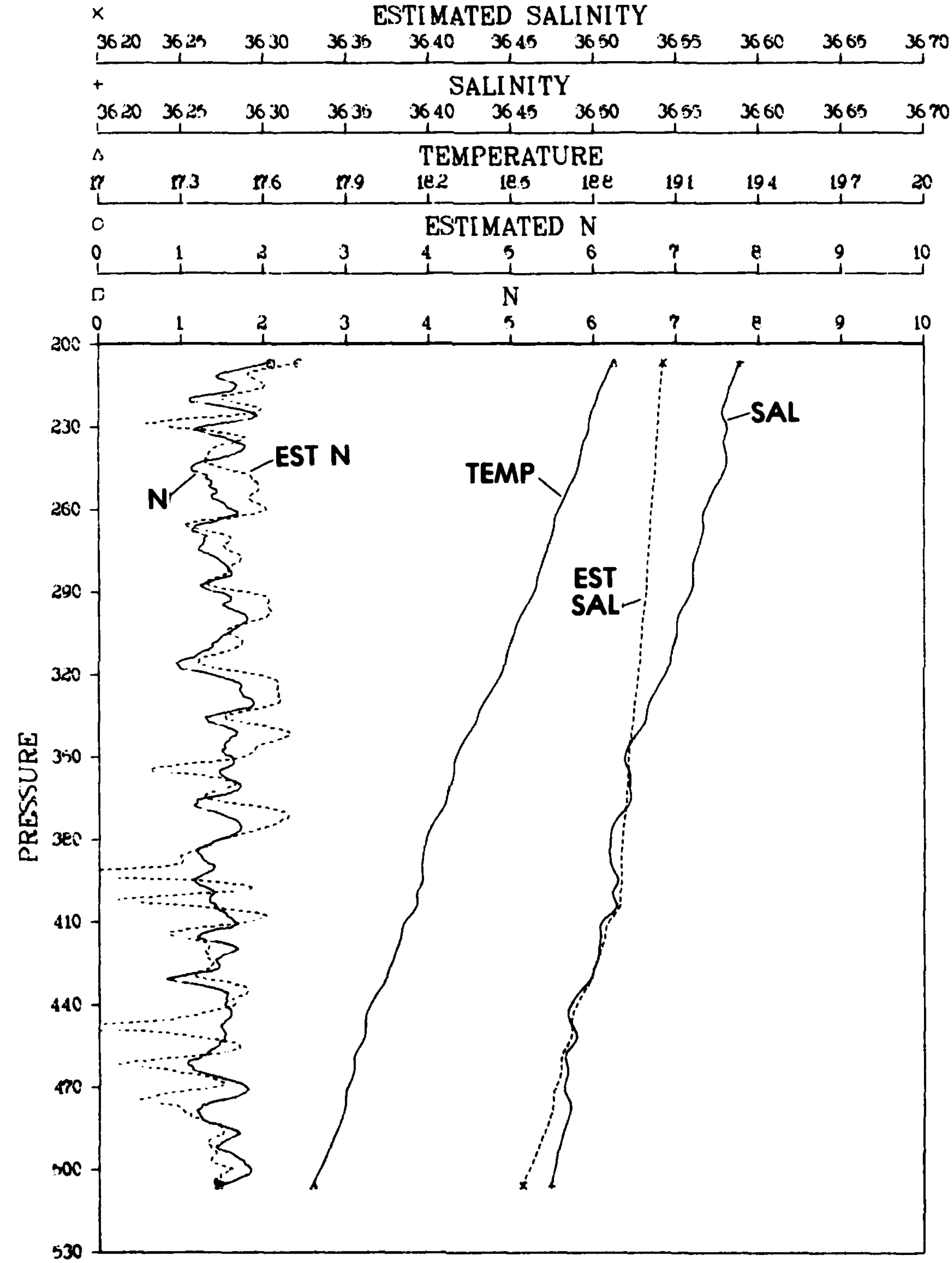

Figure 19 Average T-S method applied to cast 7 from the Sargasso Sea between 200 and 500 meters for 35 model averaged profiles

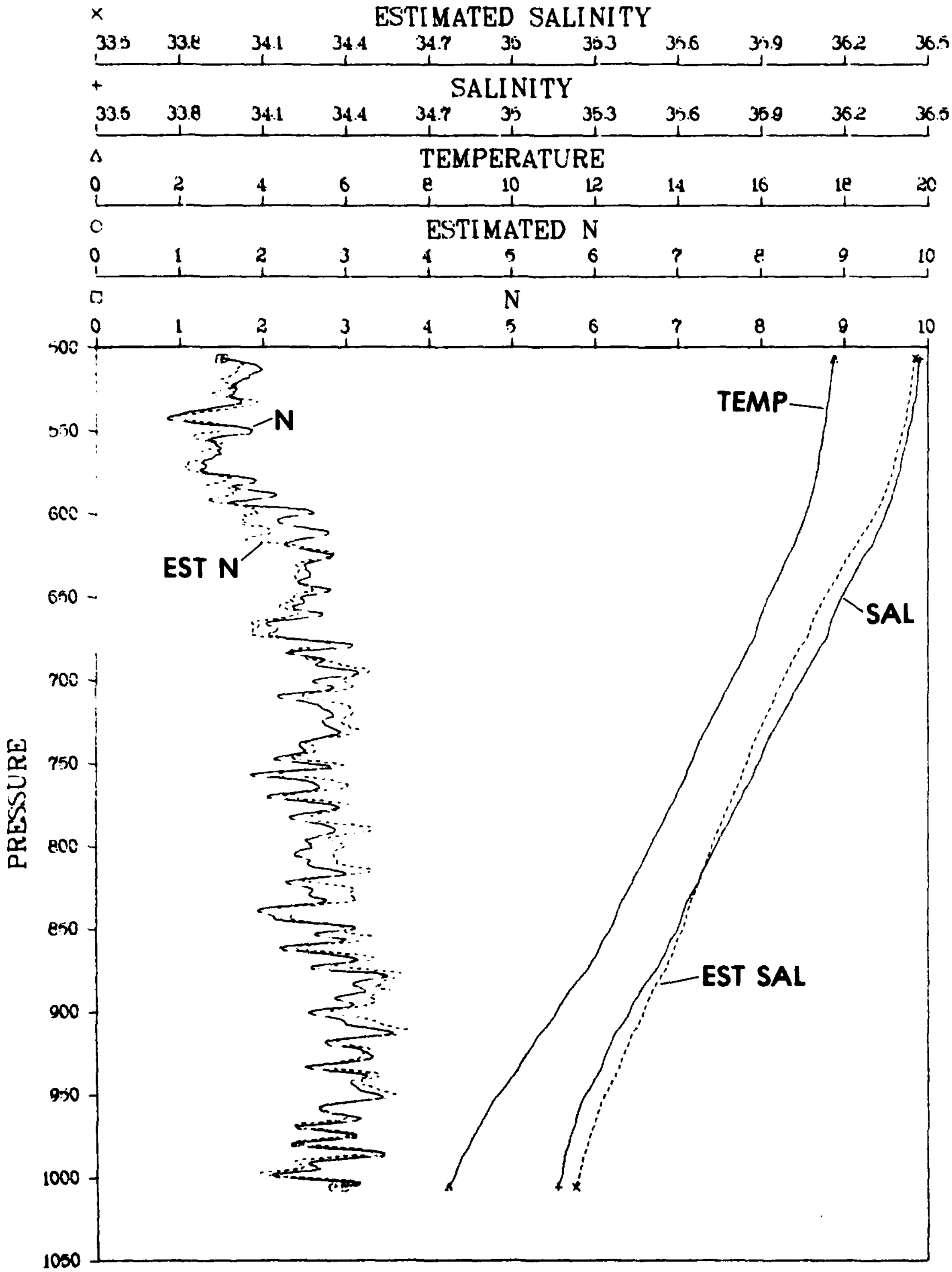

Figure 20 Average T-S method applied to cast 7 from the Sargasso Sea between 500 and 1000 meters for 35 model averaged profiles

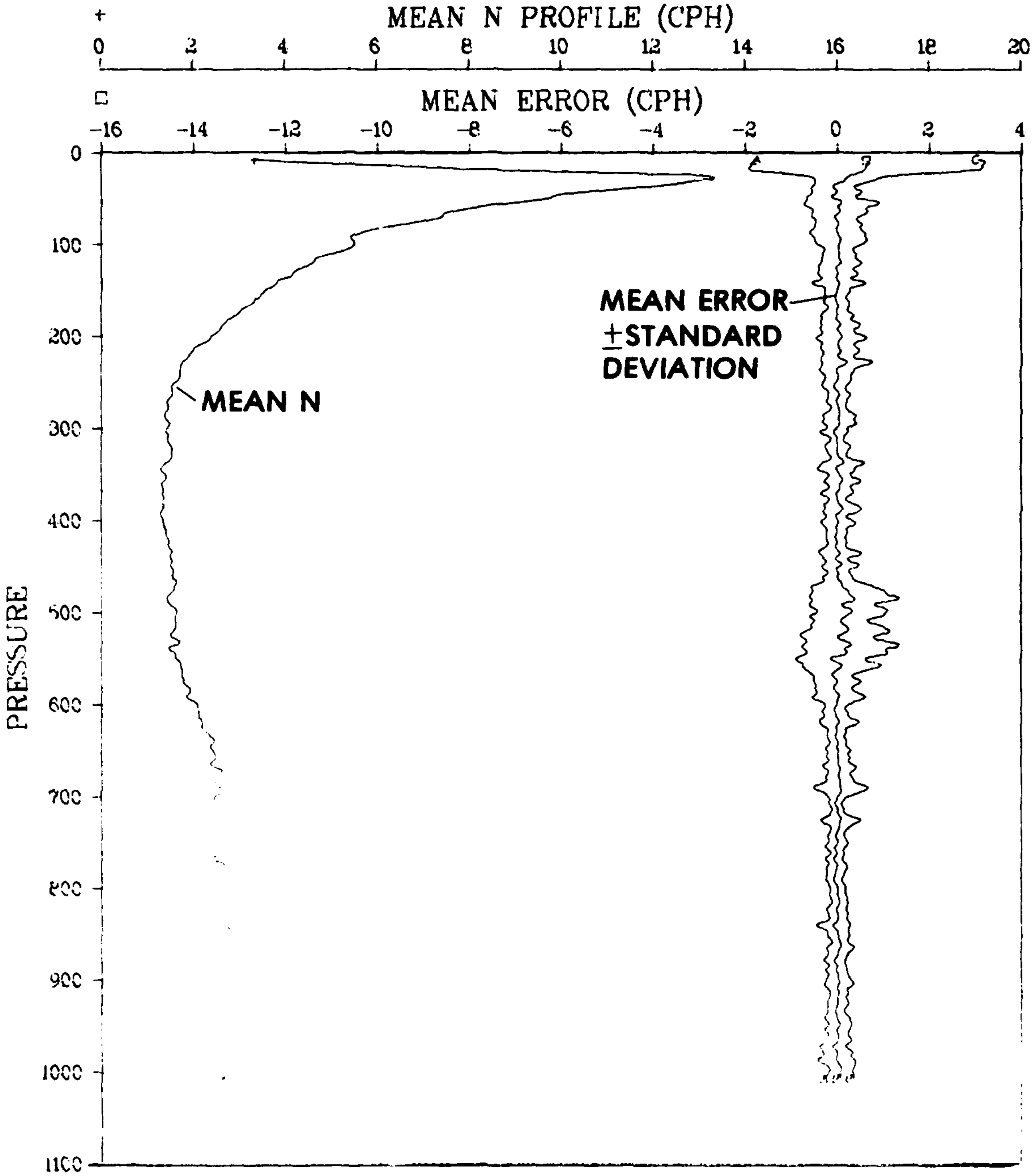

Figure 21 Mean BV frequency profile, mean error (N-Ne), and standard deviation of mean error for 31 CTD stations from the Sargasso Sea using the average T-S method

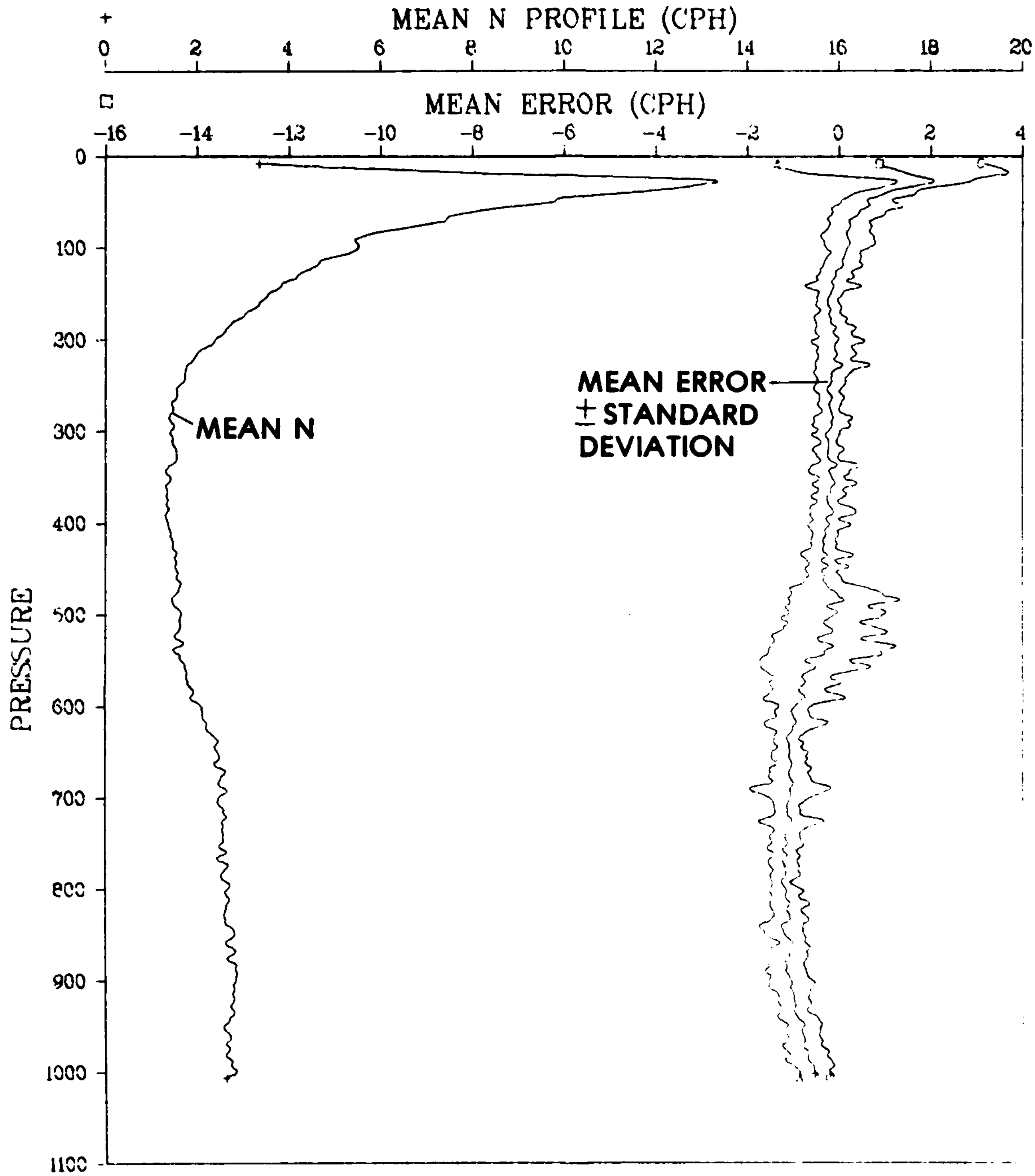

Figure 22 Mean BV frequency profile, mean error (N-Ne), and standard deviation of mean error for 31 CTD stations from the Sargasso Sea using the average S-Z method

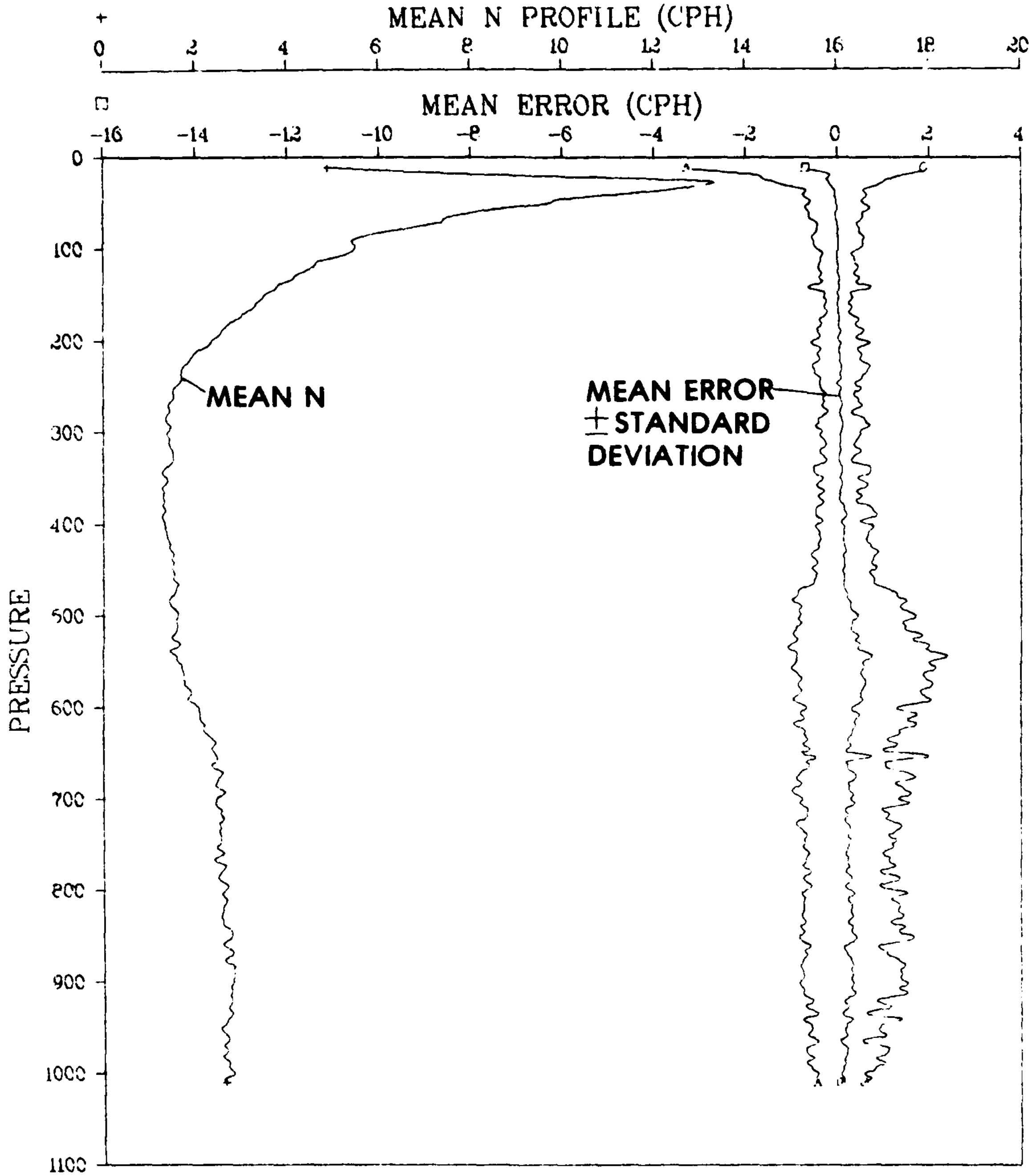

Figure 23 Mean BV frequency profile, mean error (N-Ne), and standard deviation of mean error for 31 CTD stations from the Sargasso Sea using the Constant Salinity method

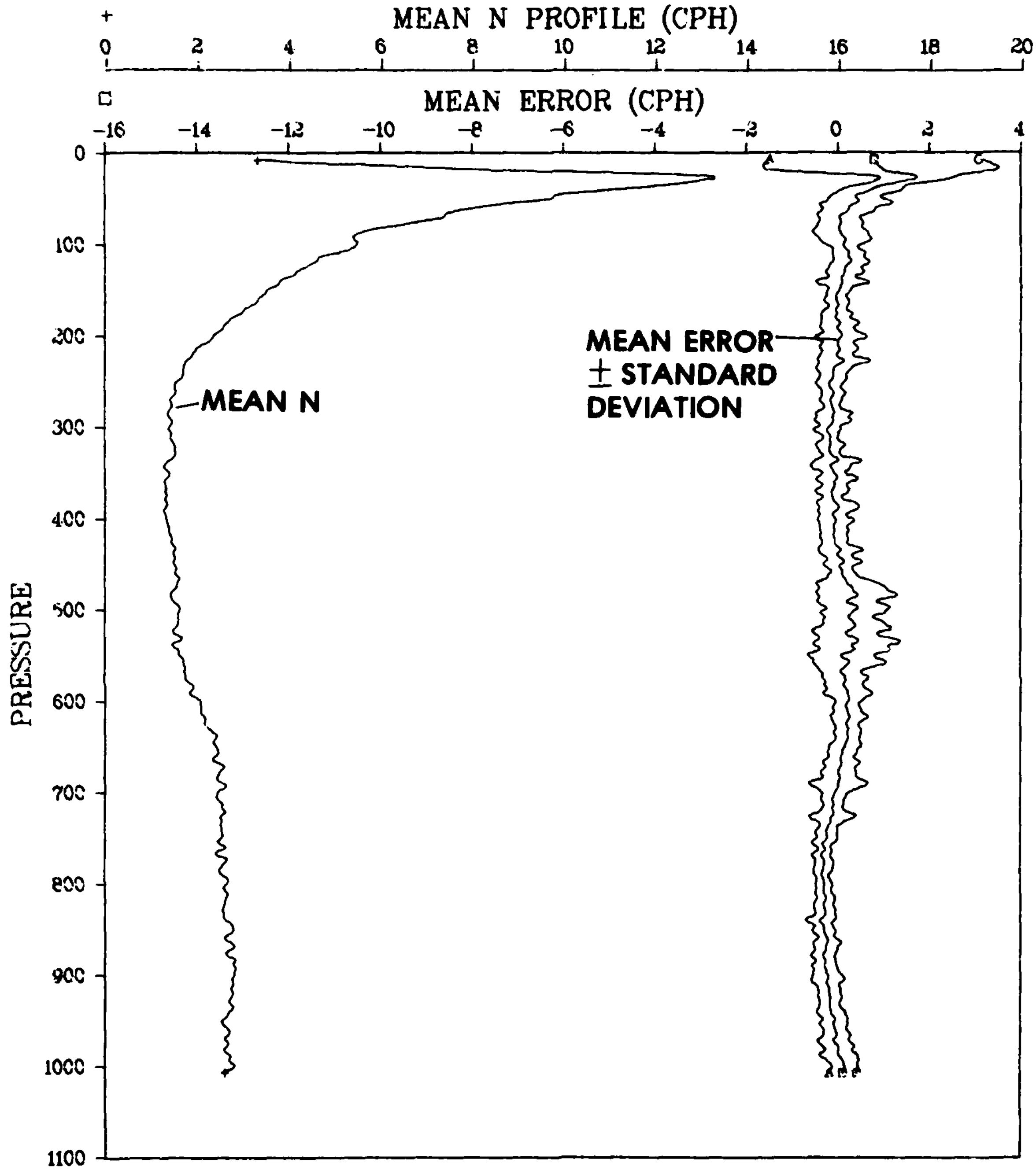

Figure 24 Mean BV frequency profile, mean error (N-Ne), and standard deviation of mean error for 31 CTD stations from the Sargasso Sea using the model average T-S method

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