PROCESSING OF OCEANOGRAPHIC STATION DATA

UNESCO

Processing of oceanographic station data

UNESCO ICES SCOR IAPSO

Processing of oceanographic station data

by

JPOTS editorial panel

Unesco

Published in 1991 by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75700 Paris

With support from

EG&G Marine Instruments
1140 Route 28A, Cataumet, Maine 02534, USA

General Oceanics, Inc.
1295 N.W. 163rd St., Miami, Florida 33169-922, USA

Printed by Imprimerie des Presses Universitaires de France, Vendôme

ISBN 92-3-102756-5

Printed in France

Notice to users of
Processing of oceanographic station data, Unesco, 1991

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Effects of the adoption of the ITS-90 temperature scale on oceanographic computations

The International Committee for Weights and Measures has adopted a new International Temperature Scale (ITS-90) during its meetings in September 1989. This newly adopted temperature scale should be used for all reported oceanographic data as of January 1990. It is of great importance that all data reports indicate specifically whether data are reported on the older International Practical Temperature Scale of 1968 (IPTS-68) or on the ITS-90 scale. The introduction of this new temperature scale has significant effects on the calculation of seawater properties when using the JPOTS recommended algorithms for the calculation of Practical Salinity (PSS-78; Unesco, 1981a, 1981b) and of the physical properties of seawater based on the International Equation of State of Seawater (EOS-80; Unesco, 1981a, 1981c). (See references on reverse side.)

The Joint Panel on Oceanographic Tables and Standards supports the recommendation of Saunders (1990) with regards the conversion of IOS-90 to IPTS-68 through the linear relationship

$$T_{68} = 1.00024 \, . \, T_{90}$$

After conversion to T_{68} the algorithms for the computation of practical salinity (PSS-78), the density of seawater, and its derived properties (EOS-80) can be used directly, as can the algorithms developed by Fofonoff and Millard (Unesco, 1983) for the computation of seawater properties.

Of importance to note are the following:

1. Temperature differences between IPTS-68 and ITS-90 (Saunders, 1990):

T_{90}/°C	-10	0	10	20	30	40
$T_{90} - T_{68}$/°C	0.002	0.000	-0.002	-0.005	-0.007	-0.010

2. Failure to make corrections from ITS-90 to IPTS-68 prior to use of the algorithms will significantly affect salinity computations, will have a lesser effect on estimated densities (mostly noticeable at higher temperatures), but will have only insignificant effects on other physical properties, e.g. compressibilities, adiabatic lapse rates, and potential temperatures (see also Fofonoff and Millard, 1991). After conversion of ITS-90 to IPTS-68 the errors in all computations become minimal and within the precision of PSS-78 and EOS-80.

JPOTS has sponsored the accompanying publication on *Processing of Oceanographic Station Data*. Tables in this manual have been prepared using IPTS-68, but temperature scales have been identified clearly. Future users of this manual are advised to note the remarks on temperature scales on page 14. Interconversion of the temperature scales will make this manual as well as the Unesco reports cited above of continued use to oceanographers.

Joris M. Gieskes
Chairman
Joint Panel on Oceanographic Tables and Standards

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Unesco 1981c. Background papers and supporting data on the International Equation of State of Seawater 1980. *Unesco Technical Papers in Marine Science* No. 38, 192 pp.

Unesco 1983. Algorithms for computation of fundamental properties of seawater. *Unesco Technical Papers in Marine Science* No. 44, 53 pp.

Preface

For almost three decades Unesco, with the support of experts from various scientific bodies, has produced and published marine scientific material, notably for the development and standardization of methods in oceanography. In 1962, the Organization aligned itself with international efforts for improvement in areas such as the standardization of salinity and density measurements when it first established the Joint Panel on Oceanographic Tables and Standards (JPOTS) together with the International Council for the Exploration of the Sea (ICES), the Scientific Committee on Oceanic Research (SCOR) and the International Association for the Physical Sciences of the Ocean (IAPSO). During the ensuing years, the JPOTS achievements in this area have been continually reported in the series *Unesco technical papers in marine science*.

JPOTS has provided a common basis for oceanographic science worldwide. However, no succinct and comprehensive text was available to help the marine scientist use the results of its efforts. Hence the reason for this text which intends to serve as recommended guidelines or a manual on how to calculate, either by computer algorithms or hand calculations, most of the common physical and dynamic properties of the sea, such as specific volume anomaly, dynamic depth anomaly, static stability, density ratio, etc.

Unesco greatly appreciates the collaboration it enjoys, through its marine science programme, with SCOR, ICES and IAPSO in striving to meet the needs of scientists around the world for consistent oceanographic data. It thanks all those who contributed to the preparation of the manuscript, particularly the members of the JPOTS Editorial Panel: H.D. Dooley, O.I. Mamayev, R.C. Millard and K. Taira. Recognition is also given to the efforts and intellectual stimulation of Selim Morcos, a Unesco staff member and consultant from 1973 to 1989, who provided much support to the JPOTS activities. He co-ordinated the development of this publication, and has maintained active interest in it following his formal retirement. The final stages of production, i.e. the assembly of the final texts, entry and updating of the text on word-processor, as well as the production of the camera-ready copy were the responsibility of H.D. Dooley, who deserves tribute for the countless hours spent before the computer.

Recognition is given to EG&G Marine Instruments and General Oceanics Inc. whose financial support contributed to the printing and distribution of this book.

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Foreword

The technological developments of the past twenty years have revolutionized the way in which physical oceanographers collect data. In particular, the development of the Conductivity Temperature Depth (CTD) profiler has produced a data explosion which has meant that computers have become essential tools for the processing of oceanographic station data, and the hand calculation methods of the past are gradually disappearing.

Unfortunately, the increasing reliance on computers has meant that physical oceanographers are becoming less familiar with the procedures that are the basis of the derivations of the fundamental physical and dynamic properties of the sea. This is particularly the case with young students of oceanography who, in the past, started on the path of earning their spurs by partaking in the "drudgery" of calculating, for example, density, geostrophic currents and vertical stability, but nowadays merely accept these numbers as given.

At a time when marine science has embarked on interdisciplinary projects on a global scale, such as those within the World Climate Research Programme (e.g. TOGA and WOCE) and the International Geosphere Biosphere Programme (e.g. JGOFS), it is important that we be reminded - and continually reminded - of the basic procedures familiar to previous generations of oceanographers so that the fundamental meaning of our measurements is not lost. The interdisciplinary nature of these projects also means that oceanographers of all disciplines can benefit from a fundamental understanding of the physical properties of the sea, and how they are determined.

It is to them, and above all to the physical oceanographers trapped in the world of computer processing of station data, that this Manual is directed.

Professor O.I. Mamayev
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Copenhagen, November 1990

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Most of this Manual was prepared by the above-mentioned and additional contributions were prepared by Peter Koltermann (section 1.3.1, pages 4 - 7) and Fred Culkin (section 1.3.2, pages 7 - 8). The Panel is grateful to Nick Fofonoff for giving permission for incorporating some of his published work in Part 1. It is also pleased to acknowledge the assistance of S. Dobroliubov and A. Pantiulin of Moscow State University in checking the hand computations described in Part 2.

Introduction

Processing oceanographic station data is an integral part of a procedure by which raw data obtained from measurements of the basic physical oceanographic parameters at an "oceanographic station", namely pressure (p), temperature (t) and salinity (S), are transformed into a form ready for analytical study, via an equation of state of seawater, into density (and its reciprocal, specific volume). From this parameter it is possible to derive the *field of mass*, and hence establish knowledge of the static and dynamic conditions of the ocean.

This task has been carried out by physical oceanographers since the inception of oceanography. It has been stimulated by a number of important milestones, including the publication of Bjerknes' theorem of circulation and the celebrated formula of Sandström and Helland-Hansen (Sverdrup, Johnson and Fleming, 1942, p. 460) as well as the publication of the concept of static stability in a multilayered ocean by Hesselberg and Sverdrup (1915). The procedures based on these works have been reflected in many tables, handbooks, and textbooks in oceanography, the most popular of them being the tables in Sverdrup, Johnson and Fleming (1942). Later, LaFond (1951) provided a comprehensive compilation of processing procedures that became the preferred processing manual for many years. However, its value has been lessened by changes in the definition of salinity and the equation of state of seawater.

A fundamental change in approach was necessary following the introduction of the bench salinometer in the 1950s. This instrument provided the means for a more precise and rapid determination of the salinity of a seawater sample by measuring its electrical conductivity. To cope with this situation Unesco, ICES, SCOR, and IAPSO formed the Joint Panel on Oceanographic Tables and Standards (JPOTS), which is the longest serving inter-organizational scientific body in oceanography. JPOTS met for the first time in 1962, and in 1965 it decided at its meeting in Rome to replace Knudsen's salinity equation, based on the gravimetric salinity/chlorinity relationship by Cox's set of equations based on the relationship between relative conductivity and chlorinity. One major outcome was a joint publication by Unesco and the then National Institute of Oceanography (NIO), UK, of the International Oceanographic Tables, Volume 1 (Unesco, 1966; Unesco, 1971) which provided a common basis for the determination of salinity by the bench salinometer.

Almost immediately after that, JPOTS was faced with new challenges arising from the rapid development and widespread use of *in situ* salinometers such as CTD (conductivity, temperature, depth) probes. These are able to measure conductivity at temperatures below 10° C, which was unfortunately the lower limit of the then-existing Volume 1 of the International Oceanographic Tables.

Moreover, new measurements and techniques led to the abandonment of the traditional equation of state of seawater at atmospheric pressure embodied in the Hydrographical Tables (Knudsen, 1901) and the equation of state of seawater at elevated pressure by Ekman (1908).

These equations were of limited accuracy but were used in oceanography for many years to compute the density of seawater as a function of salinity, temperature, and pressure.

As a result of developments in the techniques for measuring conductivity and the physical properties of seawater, the demand on JPOTS' expertise was very great from 1965 to 1978 in order to make the necessary changes to oceanographic standards and tables. At its meeting at Unesco Headquarters in Paris in September 1978, JPOTS adopted the Practical Salinity Scale, 1978 (PSS-78), (Unesco, 1979). This was followed by the adoption of the International Equation of State, 1980 (EOS-80) in Sydney, British Columbia, in September 1980 (Unesco, 1981a). Two volumes of the International Oceanographic Tables were published: Volume 3 (Unesco, 1981b), which gives values of Practical Salinity, 1978, as a function of conductivity ratio, temperature, and pressure; and Volume 4 (Unesco, 1987) entitled "Properties derived from the International Equation of State of Seawater, 1980". New algorithms for the computation of fundamental properties of seawater were also published (Unesco, 1983). In another parallel development the SUN Group on Symbols, Units, and Nomenclature in Physical Oceanography completed its report which was produced as an IAPSO/Unesco publication (Unesco, 1985). Details of the history of these technical developments are given in Morcos, Poisson and Mamayev (1990).

The International Oceanographic Tables, Volume 4 (Unesco, 1987), based on the properties derived from EOS-80, provides the basis for this Manual, as proposed by JPOTS at its meeting in the Scripps Institute of Oceanography, La Jolla, California, USA, in 1983. The proposal was brought to the attention of IAPSO at its meeting in Hamburg in August 1983, and SCOR at its meeting in Paris in September 1983. As a result SCOR suggested that a "JPOTS Editorial Panel" nominated by the sponsoring bodies might be the most efficient means for producing such a manual. At the SCOR meeting in Roscoff, France, in October 1984, the Unesco representative pointed out that "since the Manual will deal with special needs of oceanographers in developing countries, small institutions and universities, attention should be given to the expertise required of the members of the Panel." In fact the potential value of the Manual as an educational tool in oceanography was considered an important reason for its preparation.

According to the report of the SCOR Assembly of 1984, the other co-sponsors of JPOTS were invited by SCOR to take the initiative in organizing the production of an "oceanographic manual" after the style of a volume entitled "Processing Oceanographic Data", which was prepared by Dr E. LaFond (LaFond, 1951). SCOR considered that such a basic manual would provide guidance for users of the standards developed by JPOTS.

Finally SCOR, at its meeting in Seattle, Washington, USA, in 1985 approved the nomination of H.D. Dooley (ICES), O.I. Mamayev (Unesco), R.C. Millard (SCOR) and K. Taira (IAPSO) as members of the JPOTS Editorial Panel. Dr Selim Morcos represented the Unesco Secretariat.

In September 1986 the Editorial Panel held its first meeting in Moscow State University and elected Professor O.I. Mamayev as Chairman. At this meeting the basic design of the Manual was prepared and its report was published by Unesco (1986). The Panel held two further meetings, one in Copenhagen in October 1987, and then finally in Tokyo in September 1988. The progress made in these two meetings was reported in Unesco (1989). The preparation of the Manual was continued by correspondence during 1989 and at an *ad hoc* meeting of Dooley, Mamayev and Morcos in September 1989 at ICES Headquarters. Further work continued throughout 1990 by correspondence between Mamayev, Dooley, Millard and Unesco editorial staff. Final touches were made to the manuscript at meetings of the above-mentioned in November/December 1990 in Copenhagen and Paris.

An important aim of this Manual is to illustrate the similarities of and differences between "classical" reversing water bottle and present-day CTD stations from the point of view of the processing of these data. It compares the methods of the past with present-day computer procedures for deriving the fundamental physical properties of the sea. Care has been taken to follow the SUN guidelines for units in oceanography (Unesco, 1985). However, all recommendations of the SUN group have not been followed. In particular we have preserved the traditional use of dynamic metres as the measure of dynamic depth, the density anomaly (γ) is used in preference to the name density excess. The Brunt-Väisälä frequency is expressed in cph (cycles per hour) and pressure in decibars (1 dbar = 10^4 pascal) because these continue to be the most common form used in the oceanographic literature.

The Manual consists of three parts:

Part 1 gives the Scientific Background and is meant as a brief summary to update the reader on the most essential and recent developments relevant to the processing of oceanographic data.

Part 2 describes the processing of oceanographic station data and compares the results acquired from computer calculation with those derived manually. The methods of calculation of the physical properties seen most frequently in today's scientific literature are described. Some of the Fortran subroutines used to perform these calculations were taken from Unesco (1983) whilst the remainder are given in an Annex at the end of this Manual (Annex 1).Thus an important objective of Part 2 is to introduce the basics of oceanographic processing, at a time when computer processing has accelerated the transfer from raw data to the ready-to-use data.

Part 3 presents graphs which show the behaviour of the various functions, especially the non-linearity of EOS-80. In addition to their educational value, the graphs are provided as an alternative, easier way of calculating a required property other than by interpolation from the oceanographic tables.

Following Part 3 are two annexes and a comprehensive reference list of relevant publications. The first of the annexes gives details of algorithms and Fortran code computer programs of those procedures in this manual which cannot be found in Unesco (1983). The second annex (Annex 2) contains a number of tables which are supplementary to those found in the International Oceanographic Tables, Volume 4 (Unesco, 1987), hereafter referred to as IOT-4. Annex 2 can be regarded as the "Red Sea extension" to IOT-4 since it tabulates the state properties at salinities of 40, 41, 42, and 43 (the maximum salinity in IOT-4 is 40), and is reproduced here in order to facilitate the use of this Manual by marine scientists working in higher salinity areas such as the Red Sea. The potential user should, however, be aware that a salinity of 43 is beyond the range of validity of EOS-80, and Annex 2 should therefore be used with caution.

IOT-4 itself should be regarded as an integral part of the Manual, and the reader is encouraged to place this volume alongside IOT-4 on his bookshelf. If the reader does not have access to IOT-4 then it can be obtained upon request from Marine Science Publications Programme, Unesco, 75700 Paris.

We hope that this Manual will help marine scientists, particularly the younger generation of oceanographers, to acquire and maintain a scientific understanding of the procedures involved in the processing of oceanographic station data.

Part 1. Scientific background

1.1 The oceanographic station

The oceanographic station has conventionally been regarded as an observation point in the ocean at which sampling devices and/or instruments are lowered from the sea surface through the water column towards the sea bottom. This task is normally undertaken by means of a thin wire, a "hydrographic wire", lowered from a hydrographic winch on a research vessel, which is "hove to" for the time it takes to collect the observations. This may be a few minutes at stations on the continental shelf or when sampling is limited to the upper layers or several hours at stations positioned over the abyssal plains of the ocean.

The basic results of oceanographic stations are usually lists of parameter values by pressure (also a parameter), the spacing of which will depend on the number of sampling devices deployed and/or the type of instrument used. For example, a station using only reversing water bottles is not likely to have observations at more than 30 pressure levels, whereas a CTD station will acquire data on pressure (depth), temperature, and conductivity as a quasi-continuous time series. The CTD profiles have to be digitized frequently enough to allow for the influence of sensor time lags in the computation of salinity from conductivity, temperature and pressure.

Many thousands of oceanographic stations are currently occupied throughout the world's oceans each month. In the past the data from many of these stations were published in data reports, but because of a huge increase in both the number of stations, and the number of observations at each station, data are now less frequently published, but instead are stored on computer in carefully constructed data formats in institutes, and national and international data centres. However, oceanographic stations that are considered to be of value or important components of scientific expeditions are occasionally still published in data reports. This is the case for the three stations that provide the basis for this Manual.

These stations were chosen specifically because of their suitability for demonstrating the functional relationship of the observed primary parameters of pressure, temperature, and conductivity (salinity) to the theoretical values of, for example, potential temperature, density, geopotential and speed of sound. Computation of these theoretical values, or "secondary processing", forms the basis of this Manual. However, before details of these calculations are explained, the Manual briefly draws attention to the procedures required to acquire "corrected" station data. For example, temperature measured by a reversing thermometer is not *in situ* temperature: it is necessary to introduce corrections for expansion of glass and uncertainties in the manufacturing of thermometers (instrumental correction), and also for expansion of mercury due to the reduction of pressure when raising the thermometer to the surface (reduction correction).

The calculations of instrumental and reduction corrections are beyond the scope of this Manual, as are similar considerations with regard to the accurate determination of pressure and salinity; it deals only with "corrected" station data.

1.2 CTD procedures

The "classical" oceanographic station using water bottles (e.g., Nansen, Niskin) with reversing thermometers attached and clamped to a hydrographic wire has, to a large extent, been replaced over the past 15 years by electronic instrumentation such as the Neil Brown Instrument Systems E G & G Mark III CTD (Brown, 1974) which makes *in situ* measurements of conductivity, temperature and pressure at up to 31 samples per second. These are telemetered to shipboard computers which process directly to salinity and various other physical properties for plotting and listing. Water samples are also collected using a rosette multisampler to obtain chemical parameters which do not lend themselves to direct measurement, as well as being used to obtain salinity and oxygen sensor calibrations.

1.3 Standards and reversing thermometer calibrations

The high quality of pressure, temperature, and salinity data is critically dependent on good standards and calibration methods. The SCOR Working Group 51 report (Unesco, 1988) deals with calibration methods for CTD systems and the reader is referred to this document for more information. Because of specific difficulties associated with determining an accurate temperature measurement using deep sea reversing thermometers, the following section is devoted to describing the corrections to the readings of these thermometers. Reproducible standards for temperature, salinity and pressure are essential for accurate measurements, so each is discussed briefly.

1.3.1 Thermometry

The temperature field in the ocean is one of the most important sources of information that is readily accessible. It is used to determine heat transport, seasonal changes, and a variety of different mixing processes. Temperature also serves to determine, in conjunction with the salinity and pressure distribution, the mass field of the ocean which in turn is used to derive the geostrophic flow and vertical stability of layers. Thus temperature measurements of uniformly high precision and accuracy are needed over a wide range of time and space scales.

Owing to the wide range of temperature in the ocean (-2.0°C to 40°C) and the difficulties encountered in measuring precise *in situ* temperatures, the necessary accuracy and precision can easily be tailored to specific user needs. Nevertheless, basic requirements should be established in view of the need to determine long-term changes in the temperature field which require consistent accuracy and precision.

Until recently an accuracy of 0.01°C was generally accepted. With the significant advances in our understanding of the ocean interior and the abyssal circulation, an accuracy of better than 0.005°C with a resolution of 0.0005°C is now a standard requirement for CTDs.

The established technique for measuring temperature in the ocean is the Deep-Sea Reversing Thermometer (DSRT). Its accuracy is 0.01°C at the depth of reversing. DSRTs with expanded scales (say -2.0°C to 2.0°C) are now in use and allow an accuracy of 0.004°C with a precision of 0.001°C.

Combinations of thermometers protected and unprotected from the effects of pressure are used. The formula for correcting protected DSRTs has been derived by Sverdrup (LaFond,1951) and is

$$\Delta T = \frac{(T' + V_0)(T' - t)}{K - (T' + V_0) - (T' - t)} + I \qquad (1)$$

where ΔT is the correction to be added algebraically to the uncorrected reading of the reversing thermometer, T', t is the temperature at which the thermometer is read, V_0 is the volume of the small bulb and of the capillary up to the 0°C graduation, and K is a constant which for most reversing thermometers has a value of 6100. The term I is the calibration correction, which depends on the value of T'.

The equivalent formula for the correction of unprotected DSRTs is

$$\Delta T = \frac{(T'_u + V_0)(T_w - t_u)}{K} + I \qquad (2)$$

where T'_u and t_u are the readings of the unprotected DSRT and the temperature at which it is read, and T_w is the *in situ* temperature determined by the protected DSRT with which it is paired.

Pairing protected and unprotected DSRTs is done to determine the pressure (Wüst, 1933) of the thermometer reversal and thus the temperature measurement. It is obtained by taking the difference between the corrected temperatures of the two thermometers divided the pressure constant of the unprotected thermometer, expressed in temperature increase in °C per 0.1 kg/cm² increase in pressure (1 dbar).

The pressure of reversal is calculated from the expression

$$p = \frac{T_u - T_w}{Q} \qquad (3)$$

where p is pressure in dbars and Q is the pressure constant for the individual thermometer.

Detailed tables and graphs concerning DSRT correction are in LaFond (1951).

Recently, Digital Deep-Sea Reversing Thermometers (DDSRTs) have become available that, so far, seem to meet the quality standards set for classical DSRTs. Their advantage is mainly an instantaneous measurement and a digital read-out. This saves "soaking times", previously needed to adapt the thermometer to the local ambient temperature. As "soaking times" can accumulate to days of ship's time on cruises with full-profile, multiple thermometer-trip hydrocasts a trend towards DDSRTs seems imminent.

To establish the depth of the temperature measurement of the DDSRT digital pressure sensors are used in a similar configuration as with DSRTs. Instruments are available with full depth capability, and a resolution of between ±0.1 dbar and ±1.0 dbar and an accuracy of ±0.1% full scale.

Profiling instruments such as CTDs give quasi-continuous temperature measurements. A variety of sensor-types are used, with a tendency towards multiple sensors in order to detect changes in sensor behaviour. Here the same accuracy is required, since a change in temperature of 0.001°C produces a change in conductivity of 0.001 mS/cm (mS = milli-Siemens). These thermometers need to be constantly checked and routinely calibrated before and after use at sea to maintain the accuracy and resolution required. For checking calibrations *in situ*, DSRTs, DDSRTs and redundant CTD temperature sensors are used.

Thermometers, be they DSRTs, DDSRTs or CTD-sensors, need frequent calibration to document sensor performance. Platinum Resistance Thermometers (PRTs) are used as transfer standards to calibrate these thermometers. Calibration of PRTs should be done against standards such as triple-point cells in shore-based facilities.

The following three triple point cells are commonly used to calibrate PRTs:

Water at 0.0100°C,
Phenoxybenzene (diphenyl ether) at 26.8685°C,
Ethylene Carbonate at 36.3241°C.

The value assigned to the triple point of water is given on the International Practical Temperature Scale, IPTS-1968 (Barber, 1969). Other standards are available but these, perhaps with gallium (melting point at 29.771°C) as an addition, are frequently used. It is strongly recommended that calibration against triple points be regularly performed and that these triple-point cells be certified by the National Office of Standards.

Following a decision of the International Committee for Weights and Measures at its meeting in September 1989, the International Temperature Scale of 1990 (ITS-90) was approved, with effect from 1 January 1990. Thus from that date all thermometer calibrations should be undertaken using ITS-90, which was established to take advantage of technological advances and more closely approximates the thermodynamic temperature scale than the previous scales, including IPTS-68. On ITS-90 the triple point of water remains unchanged at 0.010°C; however, at standard atmospheric pressure the boiling point of water falls to 99.974°C. Over this range the relation between the temperature scales is almost linear. Consequently there are slight differences in temperature in the oceanic range of ITS-90 temperature; e.g., 10°C and 20°C corresponds to 10.002°C and 20.005°C on IPTS-68.

In summary it may be said that temperatures in the ocean are measured with a variety of instruments to the high accuracy required. With the advance of continuous measurement methods, classical deep-sea reversing thermometers have become more important as a substandard to calibrate these quasi-continuous sensors. The knowledge of how to handle and calibrate DSRTs needs to be maintained. Great care and diligence is required to establish appropriate calibration data and maintain a record of sensor performance.

1.3.2 Standard seawater

For over 80 years it has been widely accepted that greater uniformity would be achieved in salinity determinations if all laboratories used the same suitably calibrated standard. The standard adopted was IAPSO Standard Seawater, which is a filtered, natural seawater to which only distilled water has been added. The main standard has a salinity of ca 35 (P-series) and is intended for single-point calibration of bench salinometers. It is certified in conductivity ratio (K_{15}) relative to a defined potassium chloride solution and in chlorinity. Two low-salinity standards (L-series) of salinity *ca* 10 and 30 and one high salinity standard (H-series) of *ca* 38, similarly calibrated, are also available. These are suitable for checking the offset of salinometer comparator bridges at other points on the salinity scale as well as for use in low or high salinity areas. These salinity standards can be obtained, at cost, from the IAPSO Standard Seawater Service, which is operated by Ocean Scientific International Limited from the premises of the Institute of Oceanographic Sciences Deacon Laboratory, Wormley, Godalming, Surrey, UK. Until 1975 the Service was based in Copenhagen.

Standard Seawater has always been certified in chlorinity and its widespread use helped to eliminate one source of discrepancy between determinations carried out by different laboratories in the period when the chlorinity titration was routinely used for determining of salinity. In the past twenty to thirty years, however, the chlorinity titration has been replaced by the measurement of electrical conductivity for salinity determination and this has led to some major developments, including two revisions of the definition of salinity, which have been reviewed by Lewis (1980); see also Unesco (1981c). In particular, JPOTS instigated and coordinated work in several laboratories to establish relationships between salinity, conductivity ratio, temperature, pressure and density, which resulted in the adoption of the Practical Salinity Scale, 1978, and the International Equation of State of Seawater, 1980 (Unesco, 1981a).

In the Practical Salinity Scale, practical salinity is defined in terms of the ratio K_{15} of the electrical conductivity of the seawater sample, at a temperature of 15° C and a pressure of one standard atmosphere, to that of a potassium chloride (KCl) solution, in which the mass fraction of KCl is 32.4356×10^{-3} at the same temperature and pressure. This means that all conductivity ratios are referred to a defined, reproducible conductivity standard. It would not be possible to make this KCl standard solution for distribution, however, nor would it be desirable for each laboratory to prepare its own. Instead, JPOTS recommended that IAPSO Standard Seawater should in future be calibrated directly against the defined KCl solution, thus giving a means by which bench salinometers can be calibrated indirectly in accordance with the definition of

Practical Salinity. IAPSO Standard Seawater is still certified in chlorinity also, but it should be stressed that this is to be regarded as a separate independent variable relationship to salinity.

From the user's point of view, this new calibration of IAPSO Standard Seawater in K_{15} slightly simplifies the calibration of bench salinometers. The procedure is to fill the salinometer cell with Standard Seawater and either adjust the instrument to read the value of K_{15} given on the label or note the correction to be applied to give the value. It is, however, worth emphasizing a few points about the use of Standard Seawater.

1. For various reasons certain countries have established central facilities for preparing their own ampoules of secondary standard seawaters. It is strongly recommended (Unesco, 1985) that these should be calibrated directly against IAPSO Standard Seawater and not against the defined KCl standard.

2. Although every effort is made to ensure that all ampoules of IAPSO Standard Seawater are of a uniform high quality, a faulty ampoule will be encountered occasionally, the most frequent cause being the development of minute cracks at the point where the tip is sealed. It is not wise, therefore, to rely on a single ampoule when calibrating a salinometer.

3. A number of studies have shown that the chlorinity-conductivity relationship was not the same for all batches of Standard Seawater. This resulted in discrepancies in salinity results from different expeditions on which different batches of Standard Seawater were used. A recent comparison (Mantyla, 1987) of the conductivities of a wide range of Standard Seawaters, adjusted relative to the KCl standard defined in the Practical Salinity Scale, 1978, provides a means of correcting these discrepancies.

4. In reporting the results of salinity determinations, the batch number of the Standard Seawater used should also be reported.

1.3.3 Pressure

The corrections necessary to obtain pressure from unprotected reversing thermometers has already been described. CTDs use various transducers, generally a strain gauge, to measure pressure. These transducers are calibrated in the laboratory against a deadweight tester (DWT) (Fofonoff, Hayes and Millard, 1974). The DWT uses a series of calibrated weights (masses) applied to a piston of known cross sectional area to calibrate the CTD pressure transducer. A class one DWT is recommended to obtain the highest accuracy.

A series of corrections must be applied to the DWT pressure value to obtain accuracy results at the 0.02% level from class one DWTs:

a) local gravity correction from standard gravity = 9.80665 m/s^2;

b) air buoyancy correction to weights;

c) fluid head offset;

d) thermal expansion of the piston; and

e) elastic distortion of the piston with loading.

Accurate measurement of pressure is particularly important for CTD measurements, as an error of 2.5 dbar produces an error in the vertical position of the measurement as well as in salinity of 0.001. A pressure bias adjustment is important for strain gauge transducers in order to account for the variation of atmospheric pressure as well as transducer drift from station to station.

1.4 Practical Salinity Scale (1978) and the International Equation of State of Seawater (1980)

1.4.1 The Practical Salinity Scale (PSS-78)

The fundamental step in constructing the practical salinity scale PSS-78 consisted of defining a single reference point (S = 35) on the scale as having the same electrical conductivity as a reference potassium chloride (KCl) solution at 15°C and atmospheric pressure. The transition from the previous scale was made by selecting a single batch (P79) of Standard Seawater and equating the new scale to the old through the chlorinity relationship $S = 1.80655\ Cl$ for that particular batch. As the salinity on the practical scale is defined to be conservative with respect to addition and removal of water, the entire salinity range is accessible through precise weight dilution or evaporation without additional definitions. However, the practical scale is defined in terms of conductivity ratio and not by its conservative properties. Thus the second part of the definition was constructed by measuring the conductivity ratio to the KCl standard or an equivalent secondary standard over the entire range of salinities (1 to 42) of samples prepared by evaporation or dilution of batch P79 SSW and computing an empirical formula $S = S(R_{15})$, where R_{15} is the conductivity ratio at 15°C and atmospheric pressure to the KCl standard. Thus salinities on the PSS-78 scale are defined by conductivity ratios alone. Salinities determined by any other method would not necessarily coincide with the PSS-78 scale and would have to be identified separately. Lewis and Perkin (1981) and Mamayev (1986) discuss differences between PSS-78 and previous scales and provide algorithms and tables to convert existing data to the new scale.

The algorithm for converting conductivity ratio to salinity is constructed in terms of the conductivity ratio R defined as

$$R = C(S, t, p)/C(35, 15, 0) \tag{4}$$

where $C(S, t, p)$ is electrical conductivity as a function of salinity S, temperature t and pressure p. The ratio is factored into the functions

$$R = r_t(t) \cdot R_t(S, t) \cdot R_p(R, t, p) \tag{5}$$

where

$$r_t(t) = C(35, t, 0)/C(35, 15, 0)$$
$$R_t(S, t) = C(S, t, 0)/C(35, t, 0)$$
$$R_p(R, t, p) = C(S, t, p)/C(S, t, 0)$$

Salinity is given by the function

$$S = \sum_{n=0}^{5} \left[a_n + \frac{\Delta t}{1 + k\Delta t} b_n \right] \cdot R_t^{n/2} \tag{6}$$

with coefficients

$a_0 = +0.0080$	$b_0 = +0.0005$	$k = +0.0162$
$a_1 = -0.1692$	$b_1 = -0.0056$	$\Delta t = t - 15$
$a_2 = +25.3851$	$b_2 = -0.0066$	
$a_3 = +14.0941$	$b_3 = -0.0375$	
$a_4 = -7.0261$	$b_4 = +0.0636$	
$a_5 = +2.7081$	$b_5 = -0.0144$	

At $t = 15°C$ (6) reduces to the formula defining the practical salinity scale (Perkin and Lewis, 1980).

The factors r_t and R_p are given by

$$r_t = \sum_{0}^{4} C_n t^n \tag{7}$$

where

$C_0 = +0.6766097$	$C_3 = -6.9698E-7$
$C_1 = +2.00564E-2$	$C_4 = +1.0031E-9$
$C_2 = +1.104259E-4$	

and

$$R_p = 1 + \frac{e_1 p + e_2 p^2 + e_3 p^3}{1 + d_1 t + d_2 t^2 + (d_3 + d_4 t) \cdot R} \tag{8}$$
$$= 1 + \frac{C}{B + AR}$$

with

$$\begin{array}{ll} e_1 = +2.070E\text{-}5 & d_1 = +3.426E\text{-}2 \\ e_2 = -6.370E\text{-}10 & d_2 = +4.464E\text{-}4 \\ e_3 = +3.989E\text{-}15 & d_3 = +4.215E\text{-}1 \\ & d_4 = -3.107E\text{-}3 \end{array}$$

for temperature in °C and pressure in dbar.

Given a measurement of R, t and p, salinity is computed by solving (5) for R_t; $R_t = R/(r_t R_p)$ and evaluating S from (6). If conductivity ratio R is required given S, t and p, the ratio R_t can be found by numerical inversion of (5), and R can be found by solving the quadratic equation

$$R = r_t \cdot R_t \cdot R_P = r_t \cdot R_t \cdot \left[1 + \frac{C}{AR + B} \right]$$

or

$$R = \frac{\left[(Ar_t R_t - B)^2 + 4 r_t R_t A (B + C) \right]^{1/2} + \left[Ar_t R_t - B \right]}{2A} \qquad (9)$$

More detailed descriptions, including Fortran programs, check values, limits of validity, and tables are given in Unesco (1983).

This description of PSS-78 has been adapted from Fofonoff (1985).

1.4.2 Equation of State of Seawater (EOS-80)

The equation of state of seawater is the mathematical expression to calculate density from measurements of temperature, pressure and salinity. Virtually all the computations of density of seawater made since the beginning of the century have been based on the direct measurements of density, chlorinity and salinity made by Knudsen, Forch and Sörensen (1902), and of compression of seawater made by Ekman (1908). This equation was obtained from measurements of density of natural seawater in which the proportions of the various ions are not exactly constant. To be consistent with the new definition of the Practical Salinity, 1978, the new equation of state is based on measurements of density of standard seawater solutions obtained by weight dilution with distilled water and by evaporation. As the absolute density of pure water is not known with enough accuracy, the density of distilled water used for these measurements was determined from the equation of the SMOW (Standard Mean Ocean Water) whose isotopic composition is well-defined.

The new equation of state (EOS-80) which was adopted by JPOTS in 1981 (Unesco, 1981c) is:

$$\left.\begin{aligned} v(S, t, p) &= v(S, t, 0)[1 - p/K(S, t, p)] \\ \rho(S, t, 0) &= 1/v(S, t, 0) = A + BS + CS^{3/2} + DS^2 \\ K(S, t, p) &= E + FS + GS^{3/2} + (H + IS + JS^{3/2})p + (M + NS)p^2 \end{aligned}\right\} \quad (10)$$

where the coefficients A, B, ...N are polynomials in temperature t. Units: salinity, PSS-78; temperature, °C; pressure (p), bar; density (ρ), kg/m^3; specific volume (v), m^3/kg. These coefficients are given in Table 1.1.

Table 1.1 Coefficients for the International Equation of State of Seawater (EOS-80)

	A	B	C	D
t^0	+999.842594*	+8.24493E-1	-5.72466E-3	+4.8314E-4
t^1	+6.793952E-2	-4.0899E-3	+1.0227E-4	
t^2	-9.095290E-3	+7.6438E-5	-1.6546E-6	
t^3	+1.001685E-4	-8.2467E-7		
t^4	-1.120083E-6	+5.3875E-9		
t^5	+6.536332E-9			
	E	F	G	
t^0	19652.21*	+54.6746	+7.944E-2	
t^1	+148.4206	-0.603459	+1.6483E-2	
t^2	-2.327105	+1.09987E-2	-5.3009E-4	
t^3	+1.360477E-2	-6.1670E-5		
t^4	-5.155288E-5			
	H	I	J	
t^0	+3.239908*	+2.2838E-3	+1.91075E-4	
t^1	+1.43713E-3	-1.0981E-5		
t^2	+1.16092E-4	-1.6078E-6		
t^3	-5.77905E-7			
	M	N		
t^0	+8.50935E-5*	-9.9348E-7		
t^1	-6.12293E-6	+2.0816E-7		
t^2	+5.2787E-8	+9.1697E-10		

*Coefficients modified for calculation of steric anomaly (Table 1.2)

1.4.3 Density and steric anomalies

For most oceanographic usage the full value of density or specific volume is unnecessary. Because the maximum variation in magnitude over the oceanic range of salinity, temperature, and pressure is only 7%, a considerable improvement in numerical resolution is achieved by using anomalies of specific volume and density. The specific volume (steric) anomaly $\delta(m^3/kg)$ and density anomaly $\gamma(kg/m^3)$ are defined by

$$\begin{aligned} \delta(S, t, p) &= v(S, t, p) - v(35, 0, p) \\ \gamma(S, t, p) &= \rho(S, t, p) - 1000.0 \quad [kg/m^3] \end{aligned} \tag{11}$$

where $v(35, 0, p)$ is given by a separate formula (Table 1.2). In Unesco (1983) Fofonoff and Millard computed coefficients of the different formulas needed to retain numerical precision in evaluating δ and γ. Given the two anomalies, the values of specific volume v and density ρ are recoverable to higher precision than from the full formula for a typical single-precision computation using a 32-bit computer word length. The increased numerical resolution is particularly important in computation of static stability where small vertical gradients of density must be resolved.

Table 1.2 Coefficients for $v(35, 0, p)$ and $K(35, 0, p)$ in EOS-80

Coefficient	
$v(35, 0, p)$	$= v(35, 0, 0)[1 - p/K(35, 0, p)]$
$K(35, 0, p)$	$= E_{35} + H_{35}p + M_{35}p^2$
$\Delta K(S, t, p)$	$= K(S, t, p) - K(35, 0, p)$
	$= \Delta E_{35} + \Delta H_{35}p + \Delta M_{35}p^2$
$E_{35} = +21582.27$	$\Delta E_{35} = -1930.06$
$H_{35} = +3.359406$	$\Delta H_{35} = -0.1194975$
$M_{35} = +5.03217E\text{-}5$	$\Delta M_{35} = +3.47718E\text{-}5$
$v(35, 0, 0) = 972.662039 \times 10^{-6}\ m^3/kg$	
$\rho(35, 0, 0) = 1028.106331\ kg/m^3$	
$\rho(35, 0, 0) - \rho(0, 0, 0) = +28.263737\ kg/m^3$	

Pressure in bars

1.5 Links between temperature, salinity and density anomaly scales[1]

1.5.1 Temperature

The PSS-78 and EOS-80 are based on measurements which are in turn based on the International Practical Temperature Scale 1968 (IPTS-68, Barber,1969). Temperatures t_{48} based on a previous scale, IPTS-48, can be converted to IPTS-68 (Fofonoff and Bryden, 1975) using the formula:

$$t_{68} = t_{48} - 4.4 \times 10^{-6} \times t_{48}(100 - t_{48}) \tag{12}$$

valid in the range -2°C to 30°C, which gives the maximal difference in temperatures of 0.009°C. This difference leads to an uncertainty of 3.10 in specific gravity (3.10^{-6} in SI units) (Ibid.).

As pointed out in Section 1.3.1, the International Temperature Scale 1990 (ITS-90) came into effect on 1st January 1990. Thus all temperature data originating from observations calibrated using ITS-90 must also be adjusted to IPTS-68 before PSS-78 and EOS-80 algorithms can be applied. The adjustment required is

$$t_{68} = 1.00024 t_{90} \tag{13}$$

The use of temperature scales previous to IPTS-48 has not been documented and therefore the conversion cannot be certain.

1.5.2 Salinity

The Knudsen and the Cox salinity scales were used prior to PSS-78, which superseded both of these scales in calculations (for detailed explanation see Fofonoff, 1985). These scales were defined as follows:

1. *The Knudsen scale*

$$S_K = 0.030 + 1.8050 Cl \tag{14}$$

based (solely) on the definition of chlorinity as the chloride-equivalent mass ratio of chlorides to the mass of seawater;

---

[1]see also paragraph 2 of the Introduction in Unesco (1983).

2. *The Cox scale* (or 1969 scale: Wooster, Lee and Dietrich, 1969)

$$S_{Cox} = 1.80655\,Cl \tag{15}$$

defining salinity as proportional to chlorinity to satisfy mass conservation principle and also chosen to coincide with the Knudsen scale at salinity of 35.

The difference between these scales (i.e., the difference between (14) and (15) is

$$S_K - S_{Cox} = 0.03(1 - S_{Cox}/35) \tag{16}$$

This difference at different salinities is tabulated below (Table 1.3).

The difference between the PSS-78 and the Cox scale, $S_{78} - S_{Cox}$, has been extensively explored and tabulated in Lewis and Perkin (1981; cf. Table 2 therein) as well as Millero, Gonzales and Ward, 1976). These differences for various salinities and temperatures and at standard atmospheric pressure are shown in Table 1.3, upper line (Mamayev, 1986).

It follows from (16) that the difference between the PSS-78 and the Knudsen scale is

$$S_{78} - S_K = (S_{78} - S_{Cox}) - (S_K - S_{Cox}) \tag{17}$$

This difference is also shown for the same salinities and temperatures in Table 1.3 (lower line).

Furthermore, Table 1.3 shows the negligible difference between the PSS-78 and the Knudsen scale in the oceanic range of salinity (30 to 40), the S_K being reported to a precision of 10^{-2}.

Table 1.3 Salinity difference $10^3(S_{78} - S_{Cox})$ (upper line) and $10^3(S_{78} - S_K)$ (lower line) at standard atmospheric pressure. The difference between the Knudsen and Cox salinity, $S_K - S_{Cox}$ (formula (16)) is also shown.

t°C	Salinity					
	2	10	20	30	35	40
-2	+29	+66	+50	+18	0	-16
	+1	+45	+37	+14	0	-12
0	+27	+59	+42	+15	0	-14
	-1	+38	+29	+11	0	-10
10	+21	+41	+22	+6	-1	-8
	-7	+20	+9	+2	-1	-4
20	+20	+39	+16	+4	0	-8
	-8	+18	+3	0	0	-4
30	+22	+43	+15	+2	0	-6
	-6	+22	+2	-2	0	-2
$10^3(S_K - S_{Cox})$	+28	+21	+13	+4	0	-4

1.5.3 Density anomaly

Knudsen's equation of state at atmospheric pressure is expressed through the specific gravity anomaly ("sigma-t")

$$\sigma_t = 10^3(\rho/\rho_m - 1) \tag{18}$$

where ρ_m is the maximum density of pure water then accepted by Knudsen as equal to 1 g/cm^3.

The new equation of state, EOS-80, is expressed through the density anomaly as

$$\gamma = \rho - 1000. \quad [kg/m^3] \tag{19}$$

Solving (18) for ρ and substituting into (19) we obtain the following formula relating density anomaly γ to specific gravity anomaly σ_t :

$$\gamma = 10^{-3}\rho_m\sigma_t + (\rho_m - 1000.) \quad [kg/m^3] \tag{20}$$

Using the recently accepted value of maximum density of SMOW water, ρ = 999.975 kg/m^3 (Unesco, 1974), (20) becomes

$$\gamma = 0.999975\sigma_t - 0.025 \quad [kg/m^3] \tag{21}$$

This formula determines the main difference between the Knudsen-Ekman equation of state and EOS-80; it follows that in addition to instrumental differences, there exists between σ_t and γ a systematic numerical shift equal to 0.025 kg/m^3, values of γ being lower than σ_t (dimensions are different). Therefore direct substitution of γ for σ_t is unacceptable. "The difference must be taken into account for comparison of properties on potential density surfaces and similar graphical or numerical displays using σ_t as a variable." (Fofonoff, 1985)

The exclusion of the above systematic difference of 0.025 kg/m^3 leaves us with the remaining difference resulting from salinity scale difference as well as instrumental (and temperature scale) inequalities. These differences are shown in Table 1.4 (the sum of each pair of numbers plus +25 gives us the "total" difference between σ_t and EOS values; for details see Mamayev, 1986).

The steric anomaly, $\delta = v(S,T,p) - v(35,0,p)$, computed from the Knudsen-Ekman equation differs by less than the precision of measurement from EOS-80 values (Fofonoff, 1962b).

The differences in densities between the Knudsen-Ekman equation and EOS-80 at elevated pressures (difference between values, adjusted according to formula (21) and EOS-80 values) are shown for Standard Seawater (S = 35) in Table 1.5. Comparison at elevated pressures have to be treated cautiously.

Differences between steric anomaly and specific volume between the Knudsen-Ekman equation and EOS-80 are shown in Table 1.6, after Fofonoff (1985).

Finally, dynamic computations are not significantly affected by the difference between the Knudsen-Ekman equation of state and EOS-80.

Table 1.4 Density differences ($10^3 \Delta\rho$ kg/m^3) resulting from salinity scale differences (upper line) and the differences Knudsen - EOS-80 (lower line) at standard atmospheric pressure.

t° C	Salinity					
	5	10	20	30	35	40
-2	+16 +16	+37 -3	+29 -3	+12 -10	0 -9	-10 -5
0	+12 +20	+32 +2	+23 +3	-10 -7	0 -6	-8 -2
10	+3 +31	+16 +20	+7 +20	+2 0	+1 -8	-3 -7
20	+2 +33	+13 +26	+2 +27	0 +4	0 -8	-3 -11
30	+2 +26	+16 +11	+1 +15	-2 -1	0 -9	-2 -3

Table 1.5 Density differences ($10^3 \Delta\rho$ kg/m^3). Knudsen-Ekman minus EOS-80 for S = 35.

Pressure (dbar)	t° C			
	-2	0	4	10
0	-9	-6	-4	-7
2000	+17	+21	+20	+14
4000	+16	+20	+19	+14
6000	+8	+13	+13	
8000	+16	+21	+21	
10000	+58	+60	+56	

Table 1.6 Steric anomaly and specific volume differences between Knudsen-Ekman and EOS-80

	$\Delta\nu$ ($\times 10^{-9} m^3/kg$)	$\Delta\delta$ ($\times 10^{-9} m^3/kg$)				
S		0°C	5°C	10°C	15°C	20°C
				p = 0 dbar		
34		-1.6	-2.3	-0.3	0.7	0.1
35	-18.9	0.0	-1.0	1.2	2.5	2.0
36		1.4	0.1	2.4	4.0	3.5
				p = 2000 dbar		
34		-1.6	-0.3	4.3	6.8	6.4
35	-43.4	0.0	1.2	5.9	8.6	8.2
36		1.4	2.4	7.3	10.1	9.8
				p = 4000 dbar		
34		-1.6	-0.9	3.4	5.4	5.1
35	-41.6	0.0	0.7	5.1	7.1	6.9
36		1.5	2.0	6.5	8.7	8.5

Part 2. Processing procedures

2.1 Selected oceanographic stations

For the purpose of illustrating the techniques for processing oceanographic data, three high-quality oceanographic stations were selected for this Manual: two from the North Atlantic (a pair of stations for geostrophic calculations), and one from the North Pacific area (to illustrate the conditions in the abyssal ocean).

The Atlantic stations were stations 61 and 64 from R.V. "Endeavor" cruise 88 along 71° W across the Gulf Stream south of Cape Cod, Massachusetts. This cruise was conducted as part of the US National Science Foundation's Warm Core Rings (Gulf Stream region) Program.

Station 61 is at the Sargasso Sea side of the Gulf Stream in a water depth of 4260 m while station 64 is north of the Gulf Stream in the so-called Slope Water Region in a water depth of 3892 m. The data from these stations, along with other cruise details, have been published in Stalcup, Joyce, Barbour, and Dunworth (1985).

These stations are used in this Manual to illustrate the computation of geostrophic currents and transports since they cross the main axis of the Gulf Stream. The Gulf Stream is a high-velocity current system which travels parallel to the east coast of the United States before separating from the coast south of New England and meandering in a generally eastward direction. Dynamic height difference across the Gulf Stream is typically 1 dynamic metre which is associated with the 500 metre dip in isotherm depths between the Slope Water and the Sargasso Sea.

The oceanographic data of R.V. "Endeavor", cruise 88, stations 61 and 64, were obtained by Neil Brown Instruments Systems Conductivity-Temperature-Depth-Oxygen Profiler (Mark III CTD/O2). The profiler was equipped with a rosette of 24 1.2-litre Niskin water bottles, the salinity and oxygen samples from which were used to calibrate the CTD.

An extract of the computer listing for the upper 79 dbar of R.V. "Endeavor" station 61 is shown in Table 2.1 (see next section for explanation of this table). The complete standard horizon listings of R.V. "Endeavor" cruise 88, stations 61 and 64, are shown in Tables 2.2 and 2.3 (pages 51 and 53).

The third station was occupied by R.V. "Hakuho Maru" in the Japan Trench, which is located in the western periphery of the North Pacific Ocean. Deep and bottom water masses in this area originate from the Antarctic Circumpolar Current and are relatively uniform below 3000 dbar. The R.V. "Hakuho Maru" also used a Neil Brown CTD system which is limited in depth to 6550 dbar and the station was worked on 28 January 1987 at Station JT (33°52.9'N 141°55.8'E; depth 8960 m). The data from this station, along with other cruise details, have been published in Teramoto and Taira (1988). The complete standard horizon listing of this station is shown in Table 2.4 (page 55).

Station JT is characterized by a temperature profile which decreases rapidly with increasing pressure down to about 1000 dbar, and then decreases more slowly. There is a minimum in temperature at about 4200 dbar. Below this pressure, temperature increases slightly (0.2° C) owing to adiabatic compression. However, potential temperature decreases monotonically down to the bottom of the cast at 6500 dbar. Since the eastern and western edges of the trench are less than 5000 m deep, the decrease in potential temperature below this depth suggests that this water must enter the trench from the south along the trench axis. The oceanographic conditions at the location of these three stations can be visualized with the help of the curves of vertical distribution of temperature, salinity, and density anomaly (Figures 2.1 to 2.3, pages 40 to 42) and Θ, S diagrams, showing the distribution of water masses (Figures 2.4 and 2.5, pages 43 and 44). The characteristics of these water masses are described, e.g., in Sverdrup, Johnson and Fleming (1942) and Mamayev (1975).

2.1.1 Pressure level selection

(A) CTD filters

The material in Table 2.1 (page 49) is an extract of an original listing from R.V. "Endeavor" station 61 and was derived from data collected at 22 observations per second. The temperature and salinity data have been corrected for mismatches in sensor time constants (lag corrections), consistent with the procedures given by SCOR Working Group 51 (Unesco, 1988). Pressure averaging of the lag corrected CTD observations is performed on descending observations over 2 dbar intervals.

The pressure intervals (2 dbar) are centred on odd values of pressure because the first interval normally begins at the sea surface with zero (0) dbar gauge pressure and ends at 2 dbar with a centre value of 1 dbar. Stations starting below the surface are always averaged to pressure levels coincident with stations beginning at the surface (i.e. 3, 5, 7, etc.) so that temperature and salinity at neighbouring stations are comparable along pressure surfaces. The number of observations that go into the calculation of this average are shown in the column labeled "QUAL". It should be noted that the reciprocal of the number of observations averaged (1/QUAL) is proportional to the instrument descent rate.

In this Manual the 2 dbar temperature, salinity and oxygen data have been smoothed with a binomial filter and then linearly interpolated as required to the standard levels. The filtering of input temperature, salinity, and oxygen data t_i, S_i, and O_i to output data t, S, and O is as follows:

$$t(j) = 0.25\, t_i(j-1) + 0.5\, t_i(j) + 0.25\, t_i(j+1) \quad j = 2, \ldots, N\text{-}1 \qquad (1)$$

for the j^{th} observation level (N is number of pressure levels).

This agrees with the internationally adopted recommendations of SCOR Working Group 51 (Unesco, 1988).

The values in the listings of stations 61 and 64, which are shown in Tables 2.2 and 2.3 (pages 51 and 53) are not comparable, particularly in the upper layers, with those in Stalcup, Joyce, Barbour and Dunworth (1985), which used 10 dbar averages of temperature, salinity and oxygen. Similar differences exist between the data for station JT as published in Teramoto and Taira (1988) and the data for the same station shown in Table 2.4 (page 55)

Integral station properties such as geopotential anomaly and potential energy anomaly for machine calculations are accumulations over the summed 2 dbar pressure. The first t,S observation is taken also as the surface observation to provide a common starting point for the integration. Alternatively the reader may wish to employ the interpolation (extrapolation) algorithms described below should the oceanographic stations be presented with non-standard levels.

(B) Interpolation to standard pressures (water bottles)

To derive temperature and salinity gradients, geostrophic shear, etc., and to map oceanographic properties on constant pressure horizons from temperature - salinity - pressure observations it is necessary to refer the data to standard pressure horizons. In the case of water bottle observations, which are usually at slightly different depths at each station because of the influence of, e.g., wire angle, swell etc., interpolation techniques must be used to derive values at the required standard pressure horizons. Chosen standard pressure levels should preferably coincide with those recommended by IAPSO (see section 2.2, page 26), but the choice must finally depend on the precise objectives of the particular scientific programme.

There are two methods of interpolation that could conveniently be employed using very basic facilities. The first of these was utilized in the LaFond manual and consists of hand-drawing the vertical profiles of temperature and salinity and extracting the required data from the curves. Some scientists may consider this a very reliable method, especially if they consider that their scientific judgement on the nature of vertical changes in the ocean to be sound. The second simple method uses an arithmetically weighted average of values from depths immediately above and below the required depth. However, both of these methods have obvious drawbacks in most circumstances, and their use is not encouraged.

Standard computational methods for deriving values at standard pressures were developed in line with the increase in availability of computers in the early 1960s. One of the first to be developed was due to Rattray (1962), and later modified by Reiniger and Ross (1968) to overcome problems in the former method in areas of sharp gradients. These methods, both of which utilize Lagrangian interpolation by generating a pair of parabolas through three or four observation points, are used by many oceanographic institutes.

It is not normally necessary to use this technique for interpolating densely-sampled CTD data values at standard levels as the filter methods proposed by SCOR WG 51 (Unesco, 1988) and described in the previous section are more appropriate. However, a basic starting point for most vertical integrations of parameters is the surface, but values at this level are usually not available because of the physical constraints arising from the measuring techniques. Thus, unless a separate observation of the surface using, for example, a bucket or insulating (Petersson-

Nansen) bottle is obtained, it is necessary to extrapolate to the surface. The Reiniger and Ross (1968) method is a useful tool for achieving this as it employs a mirror-image technique to set up paired parabolas from which realistic surface values can be derived from the shallowest three data points of the profile. In the station listings presented in this Manual, however, the 0-dbar values have been derived in the manner described in the next section.

2.2 Computer processing of CTD station data

This section describes the methods used to compute the values of seawater properties from pressure-averaged CTD data reduced to "standard levels".

The data of R.V. "Endeavor" stations 61 and 64, and R.V. "Hakuho Maru" station JT are presented in Tables 2.2, 2.3 and 2.4 respectively (pages 51-55) . Each table contains heading data: ship's name, cruise number or name, station number, date, time, position coordinates, sounding depth and information on local gravity acceleration, Coriolis parameter (see Annex A1.4, page 110), and a mean pressure-averaged travel time converted to sound speed.

The left-most column in all of the tables in this part of the Manual shows standard pressure values. The standard pressure levels selected are coincident numerically with values of the IAPSO standard depth levels (Sverdrup, Johnson and Fleming, 1942, p.357). In addition the values listed in brackets [ ] were added to the IAPSO levels in keeping with Levitus (1982). The following are the listing intervals for pressure in decibars:

0	100	1000	4500
10	[125]	[1100]	5000
20	150	1200	5500
30	200	[1300]	6000
50	[250]	[1400]	6500
75	300	1500	7000
	400	[1750]	7500
	500	2000	8000
	600	2500	8500
	[700]	3000	9000
	800	3500	9500
	[900]	4000	10000

A description of the Fortran algorithms for computing all parameters except those involving integrals, gradients and the adiabatic levelling technique has been documented by Fofonoff and Millard in Unesco (1983). Starting to the left of the station listings shown in Tables 2.2, 2.3 and 2.4 (pages 51-55) the variables are categorized in four groups as follows. The 2-dbar temperature and salinity data are smoothed with a binomial filter and then linearly interpolated as required to the standard levels. The potential temperature, speed of sound, potential density anomaly, *in situ* density anomaly, and specific volume anomaly, which are also included in Tables 2.2, 2.3 and 2.4, are computed using the Fortran algorithms (Unesco, 1983). The dynamic height and potential energy are integral quantities from the surface to the pressure interval indicated and requires that surface t, S values have been obtained (by extrapolation using the well-mixed assumption if necessary; see section 2.1.1 (A), page 24). A trapezoidal integration method (see section 2.3.3, page 29 and Annex A1.3, page 107) is employed. The next five quantities: the stability parameter, potential temperature and salinity gradients, density ratio and Brunt-Väisälä frequency, involve the calculation of vertical gradients, algorithms for which are given in Annexes A1.2 and A1.3 (pages 108 and 109). Gradient quantities are, in machine calculations, estimated from a centred linear least-squares fit calculated over half the neighbouring listing intervals. A different method is used for the hand calculations (see section 2.3.3, page 29). The calculated depth involves a dynamic height correction and a latitude-dependent gravity correction (see also Table 2.7, page 61).

2.3 Hand processing of CTD (water bottle) station data

The following sub-sections present the fundamental equations that lead to the derivation of the functions calculated in Tables 2.2, 2.3 and 2.4 and explains their adaption for use in hand calculations. These latter calculations may be performed by reference to the graphs of these functions shown in Part 3, or by the Tables in IOT-4.

2.3.1 Density anomaly

The density anomaly at atmospheric pressure, $\gamma(S, t, 0)$, is defined as

$$\gamma(S, t, 0) = 1/v(S, t, 0) - 1000. \quad [kg/m^3] \tag{2}$$

where v is the specific volume.

Values of density anomaly are listed in Table I of IOT-4 (page 129) at intervals of t = 0.1°C and S = 1. These intervals permit linear interpolation with insignificant errors arising from the non-linearity of the equation of state. The procedure is, however, rather tedious and therefore not recommended for manual calculations. By way of example consider t = 21.43°C, S = 36.637 (Station 61, horizon 100 dbar). Linear interpolation (underlined values) of neighbouring Table I values gives:

t °C	Salinity		
	36	36.64	37
21.40	25.147		25.908
21.43	25.135	25.622	25.896
21.50	25.119		25.880

The result is γ = 25.622, which compares favourably with the 25.63 in Table 2.2 (page 51)

Prior to the introduction of EOS-80, it was possible to compute density anomaly (i.e., σ_t) using nomograms (see, for example, LaFond (1951), p. 17). However no new nomograms have been prepared based on EOS-80, but $\gamma(S, t, 0)$ may be calculated, as also suggested by LaFond (1951) for σ_t, by drawing lines of constant density anomaly on a t, S diagram. Such lines can be constructed easily with the help of Table XXV of IOT-4, which has been produced by means of a numerical inversion of the density algorithm.

2.3.2 Specific volume anomaly and specific volume

If $\gamma(S, t, 0)$ is known, then specific volume anomaly $\delta(S, t, 0)$ can be computed from the density anomaly ($\gamma(S, t, 0)$) by means of Table II of IOT-4 (pages 102 and 132), or by using the formula:

$$\delta(S, t, 0) = 1/[\gamma(S, t, 0) + 1000] - \nu(35, 0, 0) \qquad (3)$$

where $\nu(35, 0, 0)$ = 9.7266204 $10^{-4} m^3/kg$,

For the case of R.V. "Endeavor" station 61, 100 dbar horizon, for which $\gamma(S, t, 0)$ is 25.622 (see section 2.3.1, above) formula (3) gives $\delta(S, t, 0)$ = 235.6. Alternatively $\delta(S, t, 0)$ may be computed directly by means of Tables III, III(a), and III(b)[1] of IOT-4 (pp. 133-157), which gives 235.5, a small difference.

Detailed advice on the use of these Tables is given in IOT-4 (pp. 102-104).

Values of specific volume anomaly at elevated pressure (*in situ*) are calculated according to the formula

---

[1]The values of temperature and salinity, as originally given in Tables 2.2 and 2.3 illustrating machine computations, were rounded, for temperature, to the second decimal place. It should be noted that Tables III, III(a), and III(b), as they are presented in IOT-4, allow computation of specific volume anomaly with better precision in the sense that the third decimal place of salinity can be taken into account. Therefore salinity values were left with the third decimal place.

$$\delta(S, t, p) = \delta(S, t, 0) + \delta(t, p) + \delta(S, p) \qquad (4)$$

where $\delta(t, p)$ and $\delta(S, p)$ are temperature-pressure and salinity-pressure corrections to atmospheric values, defined by formulae (13) and (14) of IOT-4 and contained in Tables V and VI of IOT-4 respectively. They can also be determined from Graphs 1(a,b) and 2 (see pages 87 - 89).

The specific volume at such an elevated pressure is calculated according to formula (15) of IOT-4, or, simply

$$v(S, t, p) = v(35, 0, p) + \delta(S, t, p) \qquad (5)$$

where $v(35, 0, p)$, the specific volume in the "Standard Ocean", is tabulated in Table IV of IOT-4.

The hand computation of specific volume anomaly for R.V. "Endeavor" stations 61 and 64 is given in Tables 2.5 and 2.6 (pages 57 and 59 respectively). The processing of deep oceanographic stations generally contains computation of specific volume anomaly δ only and not of the specific volume v as such which, if needed, can readily be computed using formula (5). This is illustrated in the explanation of the column headings for Table 2.5 (page 56).

2.3.3 Dynamic depth (height) anomaly and potential energy anomaly

The dynamic height (geopotential) and potential energy anomalies are used in the calculation of geostrophic velocity and volume and mass transports.

If the field of mass is known, the internal field of pressure can be determined from the equation of static equilibrium

$$dD = gdz = -vdp \qquad (6)$$

where D is geopotential (J/kg or m^2/s^2), g, gravity (m/s^2), v, specific volume (m^3/kg) and p, pressure (Pascals).

Following Sverdrup, Johnson and Fleming (1946, p.408), the dynamic height anomaly ΔD, in dynamic metres (1 dynamic metre = 10 J/kg), is

$$\Delta D = 10^{-5}\int_{p_o}^{p_n} \delta \, dp \qquad (7)$$

where δ is specific volume anomaly ($10^{-8} m^3/kg$), pressure is in dbar (1 dbar = 10^4 Pascals). The factor, 10^{-5}, is required to convert between the units chosen for the variables.

Using the trapezoidal rule of integration it follows that

$$\Delta D = 0.5 \cdot 10^{-5}[(\delta_0 + \delta_1)(p_1 - p_0) + (\delta_1 + \delta_2)(p_2 - p_1) + ... + (\delta_{n-1} + \delta_n)(p_n - p_{n-1})] \quad (8)$$

where 0, 1, 2, ..., n are standard horizons for hand calculated results or individual 2-dbar observations for computer-derived values.

The potential energy anomaly, χ, in units of 10^{-5} J/m^2, is determined by the following integral (Fofonoff, 1962b)

$$\chi = 10^{-5} \int_{p_0}^{p_n} \frac{p\delta}{g} dp \quad (9)$$

where g is the acceleration due to gravity (ms^{-2}). The anomaly, χ, is used to calculate geostrophic mass transport from station data. An analogous potential, Q, can be defined, i.e.,

$$Q = 10^{-6} \int_{p_0}^{p_n} (z_0 - z)\delta dp \quad (10)$$

for calculating volume transports from station data.

The calculations for the dynamic depth anomaly and potential energy anomaly are illustrated in Tables 2.7 and 2.8 (pages 61 and 63) for R.V. "Endeavor" cruise 88, stations 61 and 64 respectively.

2.3.4 Relative geostrophic currents and volume and mass transports

The geostrophic velocity v (m/s), computed from the dynamic height difference between a pair of stations denoted here by A and B, is given by

$$v - v_r = \left. \frac{10\,(\Delta D_r - \Delta D)}{fL} \right|_A^B \quad (11)$$

where $f = 2\omega\sin\varphi$ is the Coriolis parameter (s^{-1}), ω is the angular velocity of the Earth, $7.29 \cdot 10^{-5}$ s^{-1}, φ is the latitude, L is the distance between the two stations in metres and $v - v_r$, the geostrophic velocity in m/s normal to the line joining the two stations relative to the reference pressure level p_r. The factor 10 is required if dynamic height is expressed in dynamic metres. The reference velocity v_r is generally not known. Usually it is assumed that at the reference level currents are weak. In the case of the R.V. "Endeavor" stations a reference level of 2000 dbar has been chosen.

The volume transport T_y, relative to the reference level, p_r, can be computed from the formula:

$$T_y = \int_A^B \int_{z_n}^{z_0} (v - v_r) dz dx = L \int_{z_n}^{z_0} (v - v_r) dz \quad (12)$$

where A, B are the horizontal limits and z_o, z_n the vertical limits of integration.

Substituting from (11) it follows that

$$10^6 T_y = \frac{10}{f}\int_{z_n}^{z_o}[\Delta D_r - \Delta D]dz\Bigg|_A^B$$
$$= \frac{10}{f}\int_{z_n}^{z_o} 10^{-5}\int_{p_o}^{p_n}\delta\, dp dz\Bigg|_A^B \qquad (13)$$

Integrating by parts yields

$$10^6 T_y = \frac{10^{-4}}{f}\left(z\int_{p_o}^{p_n}\delta dp\Bigg|_{z_n}^{z_o} - \int_{z_n}^{z_o} z[\frac{d\int_{p_o}^{p_n}\delta dp}{dz}]dz \right)\Bigg|_A^B = \frac{10^{-4}}{f}\int_{p_o}^{p_n}(z_o - z)\delta\, dp\Bigg|_A^B$$

where z_0 is the upper surface, p_0. In terms of the potential Q,

$$T_y = \frac{Q_B - Q_A}{10^4 f} \qquad (14)$$

The difference, $z_0 - z$, is simply the depth of the observation if z_0 corresponds to the ocean surface. The transport, T_y, is independent of the distance, L, between stations. For the units chosen, the transport is in Sverdrups, ($10^6 m^3/s$).

By a similar argument, the mass transport, M_y, is obtained from the formula

$$10^9 M_y = \int_A^B\int_{z_n}^{z_o}\rho(v - v_r)dzdx = L\int_{z_n}^{z_o}\rho(v - v_r)dz$$
$$= \frac{10^5}{f}\int_{p_o}^{p_n}\frac{p\delta}{g}dp\Bigg|_A^B$$

or

$$M_y = \frac{\chi_B - \chi_A}{10^4 f} \qquad (15)$$

For the units chosen, the mass transport is in units of 10^9 kg/s, numerically equivalent approximately to Sverdrups.

The hand computation of the geostrophic current and volume transport between R.V. "Endeavor" stations 61 and 64 is given in Table 2.9 (page 65). For these two stations the average Coriolis parameter is $\bar{f} = 0.88104 \cdot 10^{-4}$, derived from the values of the Coriolis parameter given in the headings to Tables 2.2 and 2.3. Since the distance between the two stations is 110,935 m then the value of the factor $10/fL$ in formula (11) is 1.0231 (s/m).

The value of the corresponding factor in formula (13), $10/f$ is $\simeq$ 113,502 s.

2.3.5 Potential temperature and adiabatic adjustment

As stated by Sverdrup, Johnson and Fleming (1942, pp. 63-64), the temperature that a water parcel would attain if raised adiabatically to the sea surface without gain or loss of heat to the surroundings, has been called the potential temperature (Helland-Hansen, 1912), designated Θ.

Thus,

$$\Theta = t - \Delta T_A \tag{16}$$

where t is the *in situ* temperature and ΔT_A is the amount by which the temperature would decrease adiabatically if the sample were raised to the surface. As further explained in IOT-4, p. 113, "More generally, the potential temperature can be defined as the temperature resulting from an adiabatic displacement to a reference pressure p_r that may be greater or less than the initial pressure p."

The second term on the right side of (14), ΔT_A, is in fact the integral over depth of Kelvin's adiabatic lapse rate, Γ (see page 34). The evaluation of this integral is not a straightforward procedure, and is gained by "step-wise computations" (Sverdrup, Johnson and Fleming, 1942, p. 64, Fofonoff, 1977); technical details of this integration are explained in Unesco (1983). The first tables for adiabatic computations were compiled by Helland-Hansen (1930) and were used in physical oceanography until they were superseded by the tables in IOT-4. These new tables have a somewhat different form of presentation and are based on recent data on thermal expansion, i.e. EOS-80, and the specific heat (c_p) of seawater.

The method for calculating potential temperature in the case of a parcel of water being raised or lowered is incorrectly described in IOT-4 (pp. 114-115) using Tables XVII to XXI. The correct procedure is as follows:

Adiabatically move a water parcel of initial temperature t_i from the initial level p_i to the surface (p = 0.0) using the adiabatic cooling table (Table XVIII) with corrections from Tables XIX and XX as given in equation 44 of IOT-4. Then move this water parcel from the surface to the final pressure p_f using the adiabatic warming table (Table XXI) and equation 45 of IOT-4. Following the example given in IOT-4, pages 114-115:

$$p_i = 3000 \text{ dbar}; \; T_i = 3°\text{C}; \; S_i = 33; \; p_f = 6000 \text{ dbar}$$

$$\Theta(S_i, t_i, p_i, p_f) = \Theta(S_i, t_o, 0.0, p_f)$$

where t_o is obtained from the adiabatic cooling table XVIII using equation 44.

1. Adiabatically raise the water parcel to the surface.

$$t_0 = \Theta(S_i, t_i, p_i, 0)$$

$$\Theta(S_i, t_i, p_i, 0) = \Theta(35, t_i, p_i, 0) + \Delta\Theta_1(S_i, 0, p_i, 0) + p_i \cdot \Delta\Theta_2(S_i, t_i, 10000, 0)/10000$$

Tables:		XVIII	XIX	XX
Θ(33,3,3000,0)	= t_o =	2.749	+0.010	+ 3 • (-0.002) °C

t_o = 2.7584°C (2.758474°C direct)

2. Adiabatically lower from the surface to the final pressure level using the adiabatic warming table (Table XXI) and equation 45.

$$\Theta(S_i, t_o, 0.0, p_f) = \Theta(35, t_o, 0, p_f) - \Delta\Theta_1(S_i, 0, p_i, 0) - p_i \cdot \Delta\Theta_2(S_i, t_o, 10000, 0)/10000$$

Tables:		XXI		XIX	XX
Θ(33, 2.7584, 0, 6000)	=	3.396	-	0.018	-0.6 • (-0.002)°C

Θ(33, 3, 3000, 6000) = 3.3791°C (3.3784°C direct)

Note the agreement to within 0.0007°C between table derived and direct machine calculations compared with IOT-4 difference of 0.004°C.

The corresponding calculations for station data are presented in this Manual in Tables 2.10, 2.11 and 2.12 using data from station JT of R.V. "Hakuho Maru".

Computations such as these are used to study the adiabatic movements of water masses of constant Θ or σ_Θ (potential density anomaly) through the abyssal ocean.

Table 2.10 (page 67) illustrates hand computations of potential temperature and also gives the increment ΔT_A of temperature during the process of adiabatic raising (cooling) to the sea surface.

Table 2.11 (page 69) presents the hypothetical example of the "back" lowering (i.e., adiabatic warming) of water with an "initial" temperature of 1.063° C at the sea surface, to a depth of 6500 dbar (1.063° C is the potential temperature of water at this pressure at station JT). This table serves to illustrate a consequence of the step-wise computation procedure referred to above in creating a difference in the increments ΔT_A, at intermediate depths, in the case of lowering as compared with raising a water parcel. These increments become equal at the bottom depth of adiabatic back-and-forth movements, i.e., 6500 dbars in this case, where ΔT_A is 0.638° C (or 0.639° C).

The calculations in Tables 2.10 and 2.11 utilize Tables XVIII, XX and XXI in IOT-4 which are limited to temperatures of ≤15° C. Since the upper 400 dbar at station JT have a higher temperature than this, the corresponding tables in Annex 2 (the "Red Sea extension") are used for the upper part of this station in Table 2.10.

Table 2.12 (page 71) illustrates an example of hand computation of adiabatic warming during the lowering of parcels of water from 1000, 1100, 1200 dbar, etc., to 6000 dbar. The basis of these computations is the Θ of each level, taken from Column 7 of Table 2.10. The table is restricted to depths ≥ 1000 dbar because the adiabatic lowering to abyssal depths of waters whose temperature is higher than that encountered at shallower depths is unrealistic.

2.3.6 Vertical stability and Brunt-Väisälä frequency

A number of methods are commonly used by the oceanographic community to estimate vertical stability. Two of these, the adiabatic levelling technique (Bray and Fofonoff, 1981) and the classical method by Hesselberg and Sverdrup (1915) are utilized in this Manual. The first method is used in the computer calculations of station profiles, demonstrated in Tables 2.2 to 2.4 and referred to therein; the second method is utilized in the hand calculations described in this section and shown in Table 2.13 (page 73) for R.V. "Hakuho Maru" station JT. A comparison of machine calculations for these two methods for computing vertical stability is given in Millard, Owens and Fofonoff (1990).

Stability using the Hesselberg-Sverdrup method is calculated from the formula:

$$gE = \rho g^2\left[-\alpha\left(\frac{dt}{dp} - \Gamma\right) + \beta\frac{dS}{dp}\right] = N^2 \tag{17}$$

where g is the gravity acceleration, $E = (1/\rho)(d\rho/dz)$, is the so-called "stability parameter", α, ß, are the coefficients of thermal expansion, saline contraction, and Γ the adiabatic lapse rate, i.e.

$$\alpha = -\frac{1}{\rho}\frac{\partial\rho}{\partial t},\quad \beta = \frac{1}{\rho}\frac{\partial\rho}{\partial S},\quad \Gamma = \frac{T}{C_p}\frac{\partial v}{\partial t} \tag{18}$$

where $T = t + 273.15$ is the absolute temperature (Kelvin) and C_p is the specific heat. The values of α, ß and Γ, are functions of t, S and p, and are calculated according to the formulae:

$$\alpha(S, t, p) = \alpha(S, t, 0) + \Delta\alpha'(t, p) + \Delta\alpha(S, p) \tag{19}$$

$$\beta(S, t, p) = \beta(S, t, 0) + \Delta\beta'(S, p) + \Delta\beta(t, p) \tag{20}$$

$$\Gamma(S, t, p) = \Gamma(S, t, 0) + \Delta\Gamma'(t, p) + \Delta\Gamma(S, p) \tag{21}$$

where the Δ terms are the temperature-pressure and salinity-pressure corrections to the values at atmospheric pressure. The derivation of formulas (19) - (21) can be found on page 86. An example of the hand computation of these parameters is shown in Table 2.13.

As shown in equation 17, the stability is proportional to N^2, which is the square of the Brunt-Väisälä frequency, the natural frequency of oscillation for a water parcel displaced adiabatically from its rest position. A number of different methods have evolved over the years to estimate N and these are described in Millard, Owens and Fofonoff (1990).

2.3.7 Density ratio

The density ratio, R_ρ, is defined as the ratio of the thermal part of stability to its salinity part, i.e.

$$R_\rho = \frac{\alpha\,(dt/dp)}{\beta\,(dS/dp)} \approx -\frac{E_t}{E_S} \tag{22}$$

where α and β are the coefficients of thermal expansion and saline contraction, respectively, (α/β is the isopycnal derivative) (see previous section). The reverse ratio, $-(E_S/E_t)$, is also found in the scientific literature.

The density ratio shows the relative influence of temperature and salinity on the thermohaline stability in the ocean as an indication of the character of internal mixing processes and water mass formation. The use of this oceanographic variable is demonstrated *inter alia* in Schmitt (1981). It is postulated that the density ratio within the Central Water Masses (or Mode Waters) of the oceans are nearly constant in each ocean (*loc. cit*). In the case of the Gulf Stream region the density ratio at depths of 100-1000 m (Central Waters) is around -2.0, but cannot be proved directly for the Kuroshio region.

The results of the machine computation of density ratio are given in Tables 2.2, 2.3 and 2.4 (pages 51-55) and of the hand computations in Tables 2.14, 2.15 and 2.16 (pages 75-79).

2.3.8 Potential vorticity

The potential vorticity (Q) for the simple case of a homogeneous ocean, or a layer with a depth H is (see, e.g., Stommel, 1966, p. 108):

$$Q = \frac{f + \zeta}{H} \tag{23}$$

where f is the Coriolis parameter, $\zeta = \partial v/\partial x - \partial u/\partial y$ is the relative vorticity introduced by horizontal current shear.

Rossby (1940) extended the idea of potential vorticity to multilayered systems including the case of a continuously stratified fluid. For conditions of small horizontal current shears, ζ can be ignored ($f >> \zeta$), and potential vorticity can be expressed as:

$$Q = \frac{f}{\rho_\theta}\frac{d\rho_\theta}{dp} = fE \tag{24}$$

where ρ_θ is potential density and E is the stability parameter. The theoretical derivation of this equation can be found in, for example, Luyten, Pedlosky and Stommel (1983).

The potential vorticity of a column of water is conserved for a frictionless ocean. This is a property which makes it a useful tool for studies of dynamical tracer of water mass movements and their transformation under different circumstances. The practical use of potential vorticity in ocean circulation and water mass studies, including ways of selecting isopycnal layers for its calculation, can be found in e.g., Keffer (1985) and Talley (1988).

The potential vorticity is not included in Tables 2.2 - 2.4, as it is proportional to E, with constant of proportion f (see formula (24)), but is included in Tables 2.14, 2.15 and 2.16 (pages 77 to 79).

2.3.9 Speed of sound

According to the theory of sound-wave propagation (Lamb, 1932), the speed of sound is given by the formula

$$c^2 = (dp/d\rho)_A \tag{25}$$

where $(dp/d\rho)_A$ is the reverse adiabatic density gradient in compressible fluid. In practice, however, the speed of sound is calculated using empirical formulas, such as that of Chen and Millero (1977) which is employed in this Manual. The condensed table for the speed of sound in the ocean as a function of pressure, temperature and salinity was published in Unesco (1983) and repeated in IOT-4. As the precision of sound speed of 1 m/s is adequate for echosounder correction, and other applications using this parameter are beyond the scope of this Manual, no additional detail other than that contained in Table XXIII of IOT-4, and the graphs showing the relation between the speed of sound and p, t and S (Graphs 11 and 12, pages 102 and 103 respectively), is necessary.

Graph 11 is a plot of the speed of sound against pressure, with isolines of temperature superimposed. This graph is constructed for the case $S = 35$, and the salinity corrections for deviations from 35 in the oceanic range are given in Graph 12. This form of presentation, adapted from Anon(1962) by re-plotting using the formula of Chen and Millero (1977), serves to illustrate the relative roles of temperature and pressure in determining the speed of sound. The speed of sound increases with increasing temperature, pressure and salinity (the influence of salinity is negligible). In the real ocean, pressure steadily increases with depth whilst temperature normally decreases with increasing depth, especially in the upper 1000 m, and more gradually below this. As a consequence, the influence of the decrease of temperature in the upper layers on the speed of sound is greater than the opposing effect of increasing pressure and the speed of sound therefore decreases with depth. Below the main thermocline, however, the decreasing influence of temperature on the speed of sound results in an increase in the speed of sound with increasing depth. As a result, minimum of sound speed is produced at the depth at which the influence of pressure balances that of temperature, depending on the local oceanographic conditions.

The above considerations are clear from the dashed line in Graph 11, which is the profile of sound speed from R.V. "Hakuho Maru", station JT. This example shows that the sound speed minimum at this location is at a depth of approximately 900 metres.

The "channel" of minimum sound speed acts as an acoustic waveguide, a feature which makes it possible for oceanographers to track SOFAR floats over long distances. In this channel a few watts of sound can be heard about 2000 km away (Rossby, 1979).

2.3.10 Depth-to-pressure conversion

Table 2.17 (page 81) gives pressure in decibars obtained from depth in metres for various latitudes. The table is a companion to the pressure-to-depth conversion Table XXIV of IOT-4 and is intended for converting existing station data for which only depth in metres is available.

The pressure values of Table 2.17 are obtained from numerical integration of the hydrostatic relationship

$$p = \sum_{0}^{z} g(\varphi, p')\,\rho(35, 0, p')\Delta z \qquad (26)$$

using the trapezoidal integration method.

Notice that both gravity (g) and density (ρ) also involve pressure (p') which was estimated as follows. The previous pressure estimate $p(z - \Delta z)$ is used to form a first estimate of pressure (p') in order to evaluate g and ρ.

$$p' = p(z - \Delta z) + \rho[35, 0, p(z - \Delta z)]\, g\, [\varphi, p(z - \Delta z)] \cdot \Delta z \qquad (25)$$

where φ = latitude and $g(p, \varphi)$ is gravity, the formula for which can be found in Unesco (1983), p.27, and

$$\rho(35, 0, p) = [1000 + \gamma(35, 0, p)]\ kg/m^3$$

is the density of a standard ocean of salinity 35 and temperature 0° C. $\gamma(35, 0, p)$ is the density anomaly which can be calculated from the specific volume anomaly function described in Unesco (1983). $\rho(35, 0, p)$ is also tabulated in IOT-4 (Table IV, page 158).

A comparison of $p(z)$ estimated from this algorithm with the direct substitution of pressures using the depth algorithm published in Unesco (1983) showed a maximum difference at any latitude of less than 0.1 m. This is within the stated accuracy of the depth algorithm.

2.4 Concluding remarks

At the present time, when the majority of oceanographic calculations are done by computer, the use of hand calculations might appear outmoded. Hand calculations as such are not being advocated, but they provide insight to the intrinsic meaning of the various oceanographic parameters. For example, in machine calculations of the vertical stability an appreciation of the relative contributions of the thermal expansion and saline contraction coefficients in relation to the t and S vertical gradients is lacking, as is the understanding of the relative contributions of t and S to the stability parameter.

During the preparation of this Manual the Panel was particularly concerned about the amount of work that went into the hand calculations which provide the backbone to Part 2, and, especially, to the number of computational errors that were discovered because of the availability of the corresponding computer calculations. Indeed, the intricacies of EOS-80 are such that hand calculations as a routine must be discouraged, but should be familiar to students of oceanography, as already explained. It is important that oceanographers be reminded of the fundamental properties of EOS-80, and it is to be hoped that the tables of station data presented in the Manual will provide the scientist with useful insight into its behaviour. The reader should not draw conclusions on the differences, or lack of them, between computer and hand calculations. Clearly, however, the hand calculations do produce results that are comparable with those produced by computer. For example, the integrated dynamic depth and potential energy anomalies agree to within 0.5%. Properties derived from vertical gradients in t and S, such as the stability parameter E, differ by as much as 50% locally although in general the two methods compare remarkably well for the R.V. "Hakuho Maru" station, as shown in the profiles of stability in Figure 6 (page 45).

In undertaking the preparation of this Manual, the Panel were struck by the onerous labour that must have pre-occupied previous generations of oceanographers. We are convinced that the advent of computers must have done much to advance our understanding of oceanographic processes by releasing scientists' energy to the undertaking of more creative work.

Figures and tables for Part 2

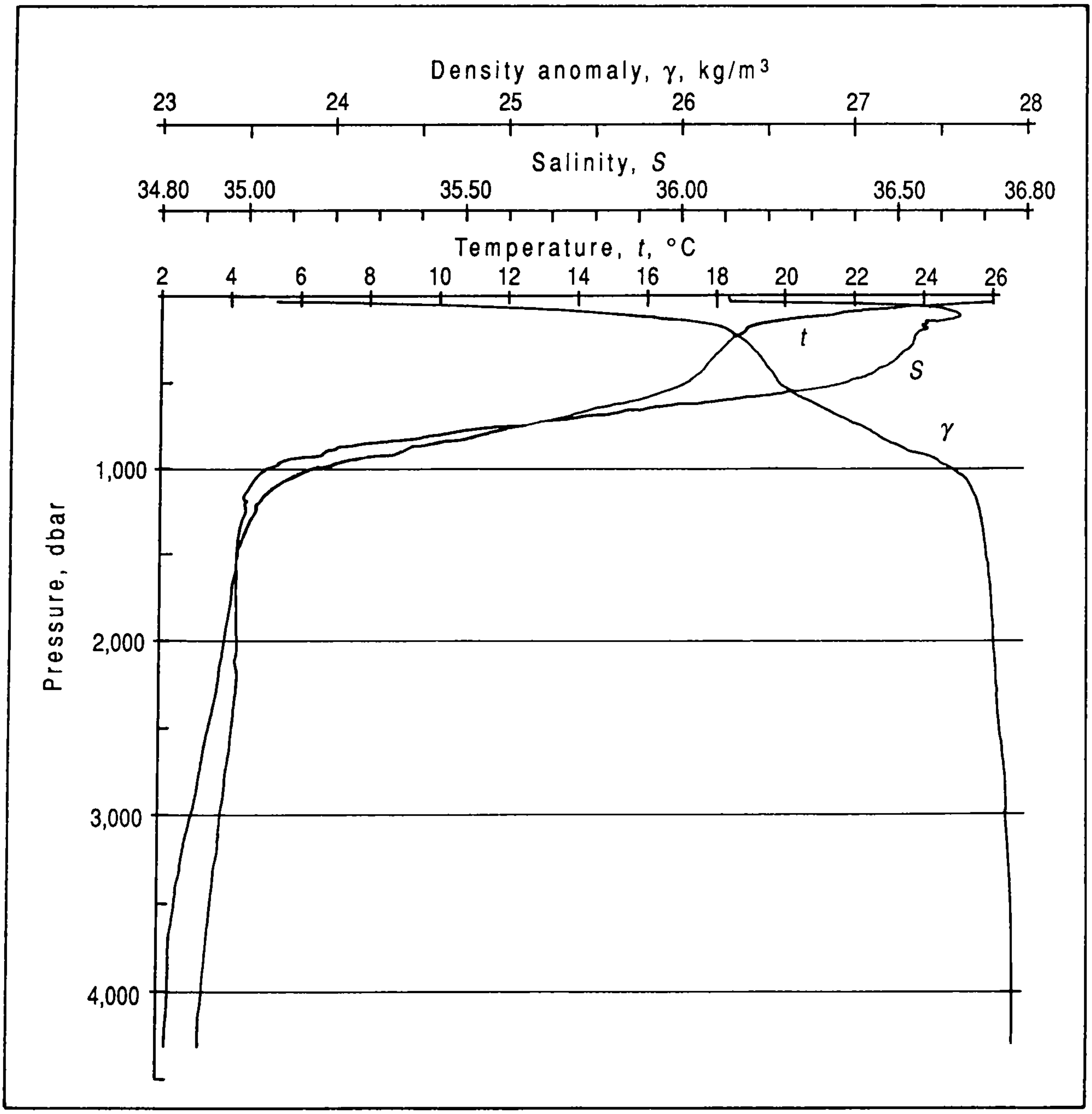


Figure 2.1 Vertical profiles of temperature, salinity and density anomaly for R.V. "Endeavor", cruise 88, station 61

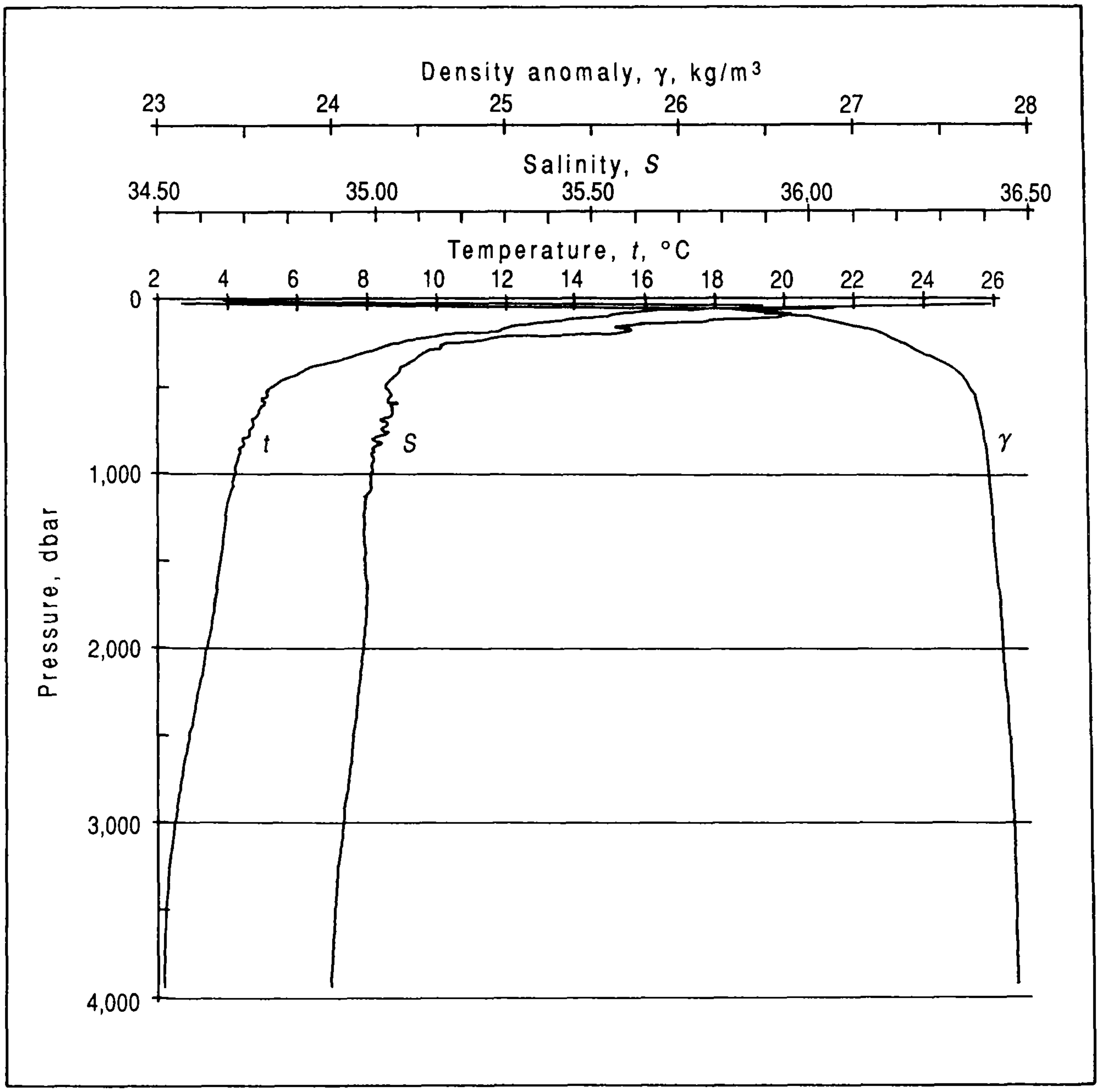


Figure 2.2 Vertical profiles of temperature, salinity and density anomaly for R.V. "Endeavor", cruise 88, station 64

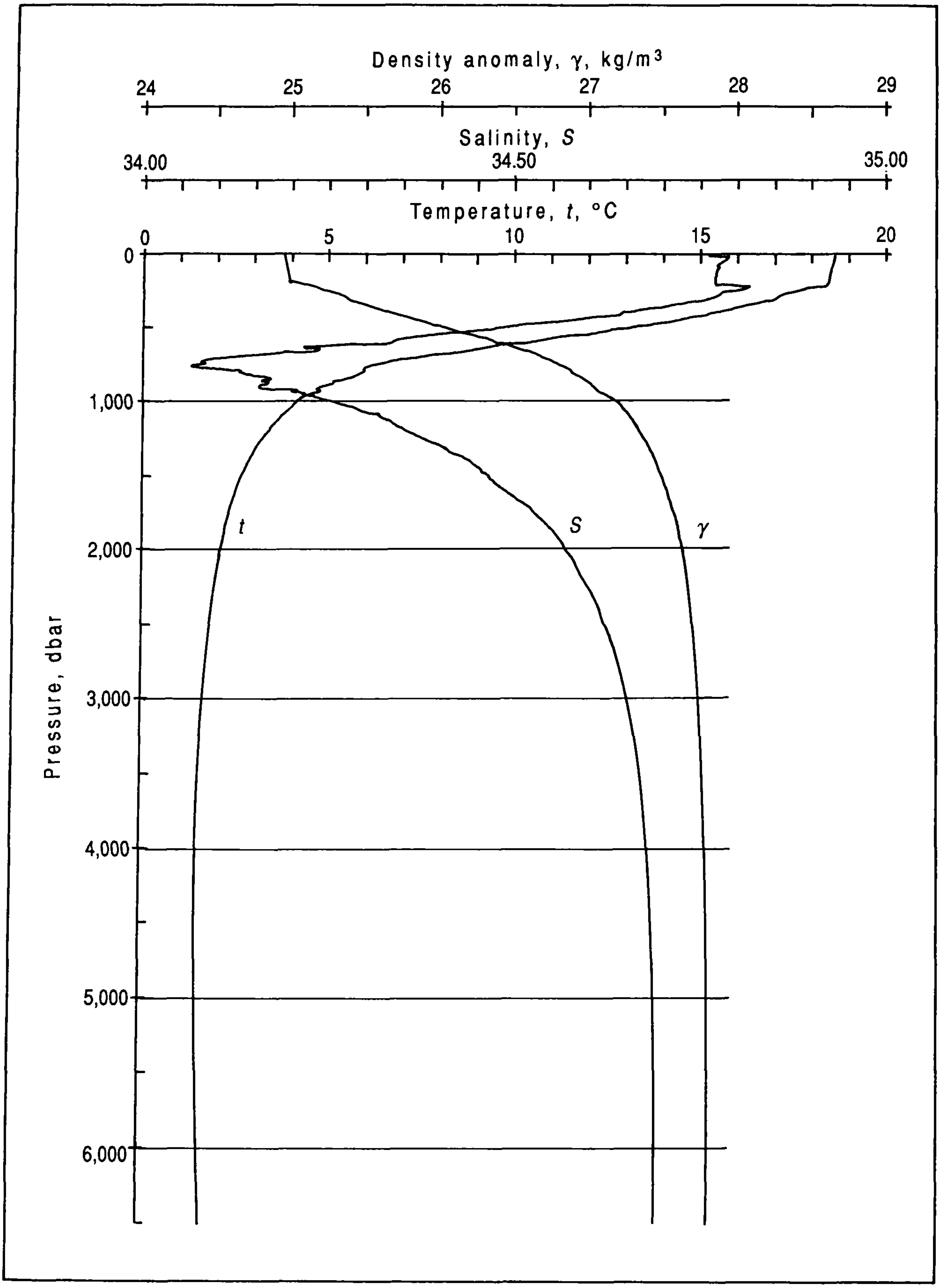


Figure 2.3 Vertical profiles of temperature, salinity and density anomaly for R.V. "Hakuho Maru", cruise KH-87-1, station JT

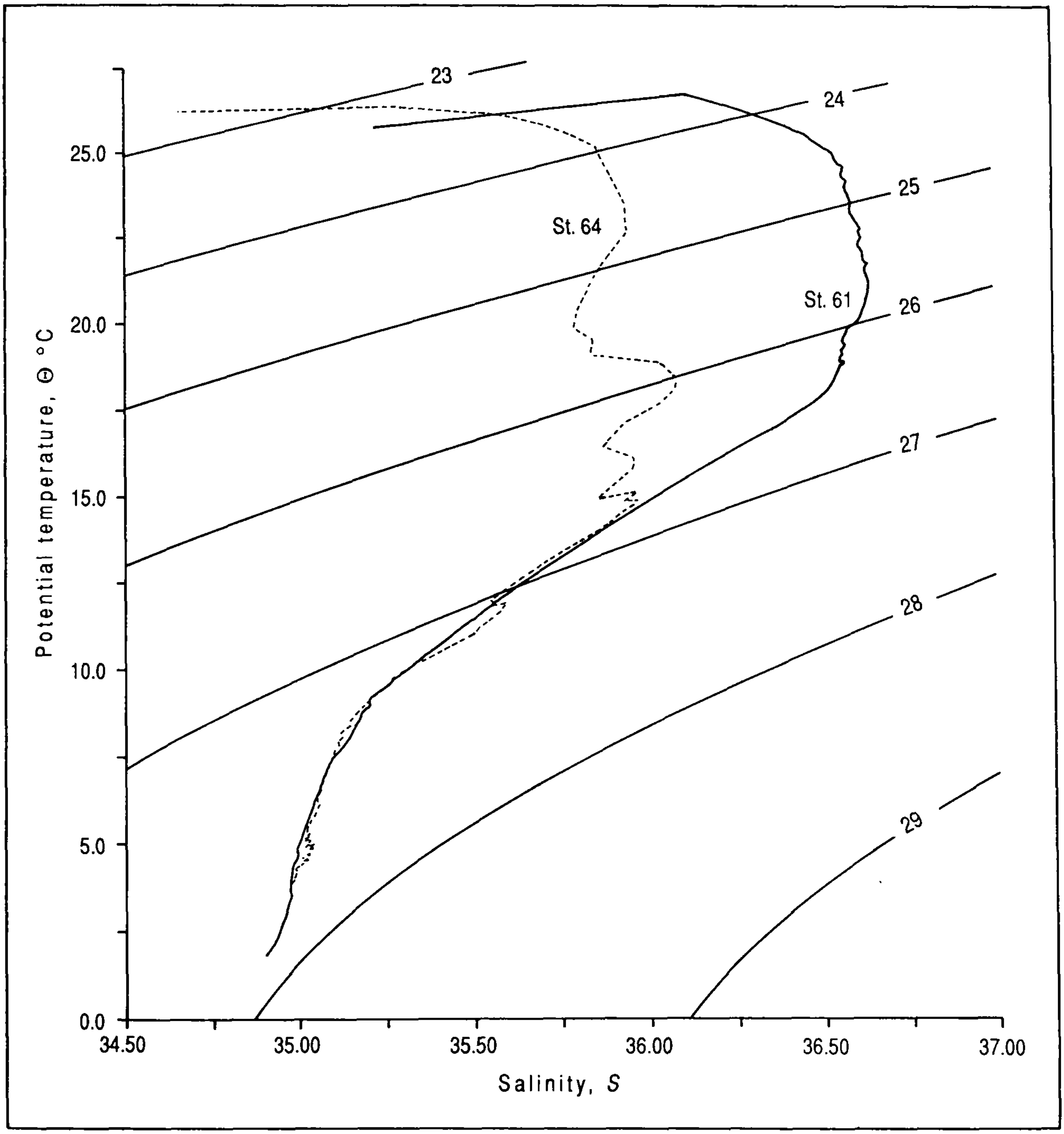


Figure 2.4 Θ, *S* plot for R.V. "Endeavor", cruise 88, stations 61 and 64

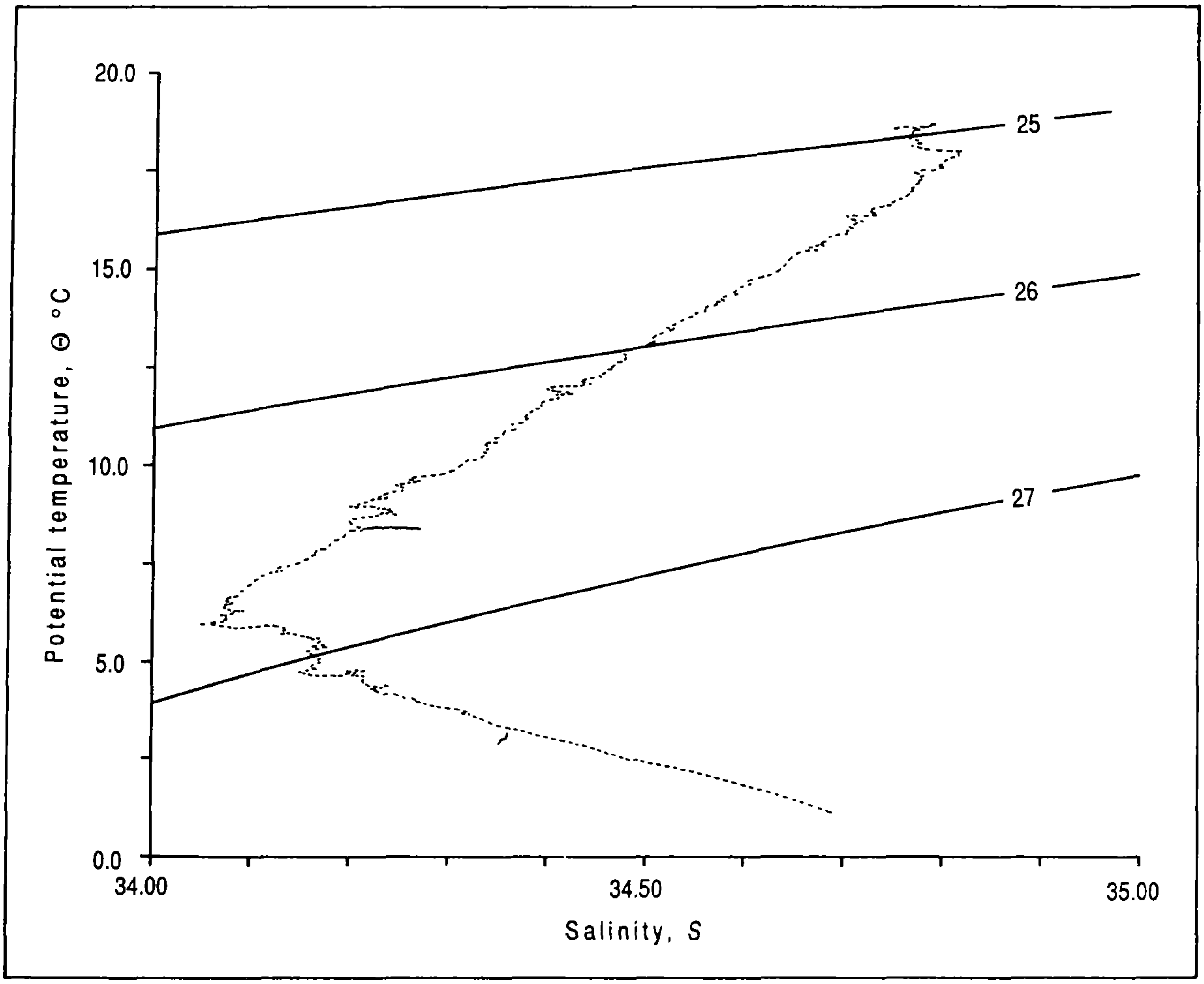


Figure 2.5 Θ, *S* plot for R.V. "Hakuho Maru", cruise KH-87-1, station JT

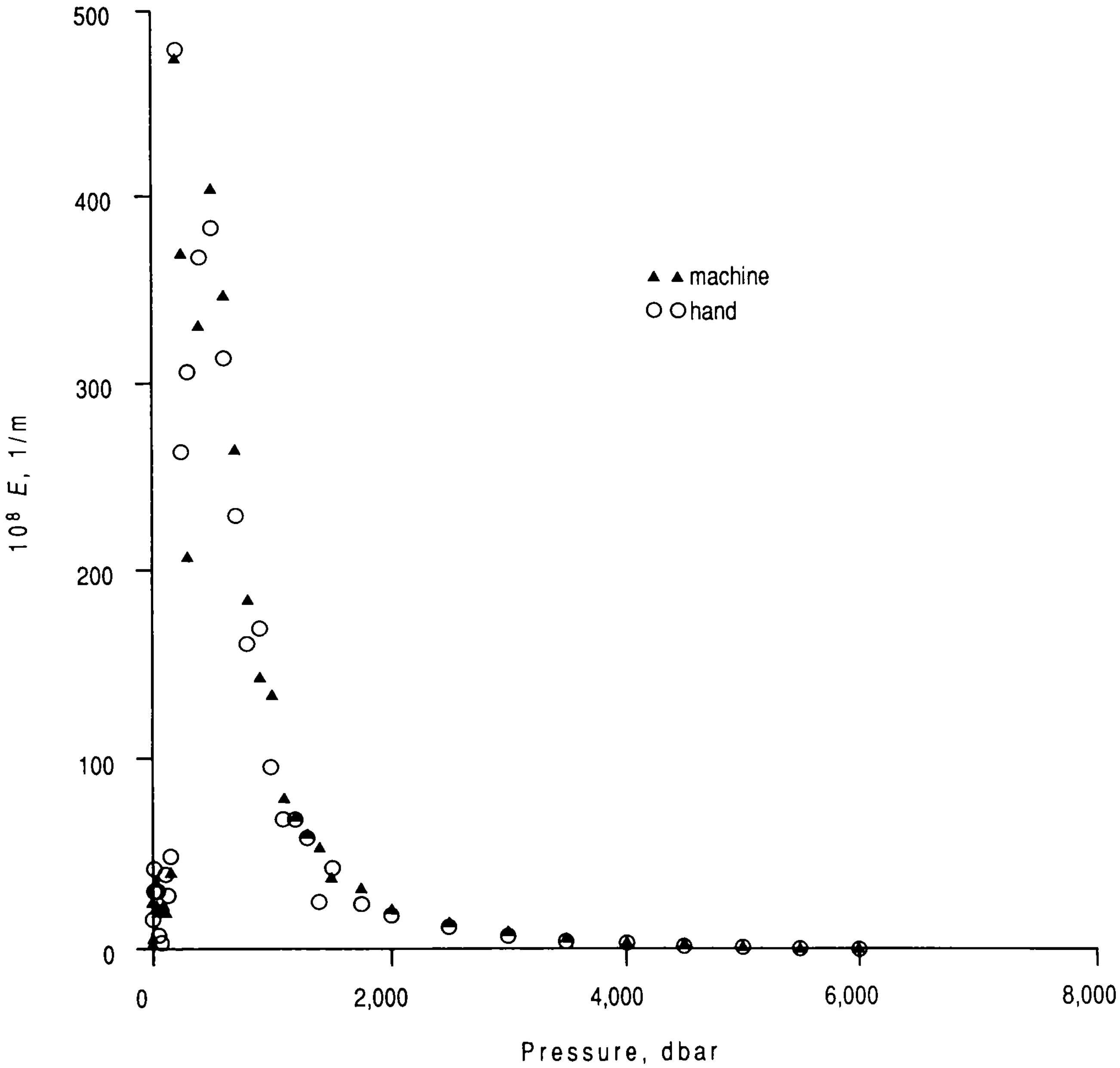


Figure 2.6 Stability (*E*) as a function of pressure for R.V. "Hakuho Maru", cruise KH-87-1, station JT

Tables for Part 2

Table 2.1 Original listing from upper part of R.V. "Endeavor" cruise 88, station 61.

SHIP EN CRUIS 88 STAT: 61 C#: 0 DATE 82- 8-23 TIME: 1102 Z LAT 36 40.03 LG -70 59.59 MAX. PRS= 4327. DB DEPTH= 4230.M AVER 2.0 INST 7 RATE 22.00HZ OBS= 2164 FMT(F7.1,2F8.4,F6.2,I6)				
PRES	TEMP	SALT	OXYG	QUAL
1.0	25.6980	35.2211	5.03	94
3.0	26.6620	36.1042	4.70	94
5.0	26.6702	36.1037	4.62	76
7.0	26.6673	36.1048	4.68	303
9.0	26.6754	36.1067	4.65	74
11.0	26.6736	36.1049	4.65	73
13.0	26.6701	36.1052	4.67	68
15.0	26.6720	36.1064	4.60	68
17.0	26.6771	36.1068	4.66	67
19.0	26.6822	36.1067	4.66	69
21.0	26.6758	36.1057	4.65	69
23.0	26.6732	36.1065	4.67	64
25.0	26.6734	36.1067	4.72	81
27.0	26.6762	36.1066	4.75	57
29.0	26.6757	36.1065	4.74	72
31.0	26.6761	36.1063	4.68	78
33.0	26.6749	36.1080	4.77	57
35.0	26.6711	36.1138	4.85	81
37.0	26.5288	36.1740	4.90	62
39.0	25.8694	36.3723	5.03	69
41.0	25.4196	36.4652	5.18	65
43.0	25.2185	36.4949	5.24	74
45.0	24.9584	36.5360	5.23	49
47.0	24.7959	36.5412	5.18	90
49.0	24.5895	36.5657	5.16	53
51.0	24.4528	36.5633	5.20	75
53.0	24.2995	36.5612	5.16	68
55.0	24.1224	36.5804	5.16	57
57.0	23.9732	36.5712	5.18	78
59.0	23.7742	36.5803	5.15	55
61.0	23.5427	36.5911	5.18	80
63.0	23.4135	36.5864	5.14	57
65.0	23.1998	36.5868	5.14	75
67.0	23.0936	36.5961	5.11	59
69.0	23.0007	36.5991	5.11	64
71.0	22.8895	36.6089	5.11	65
73.0	22.8376	36.6113	5.09	68
75.0	22.7606	36.6175	5.04	47
77.0	22.6541	36.6108	5.11	82
79.0	22.5074	36.6183	5.09	51

Table 2.2 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C calibrated on the 1968 International Practical Temperature Scale (IPTS-1968) (Barber 1969).

3 Salinity (S) computed from conductivity (C), temperature and pressure according to the Practical Salinity Scale (1978). (Unesco, 1983, pp 6-12).

4 Potential temperature (Θ) in °C computed by integrating the adiabatic lapse rate (Bryden, 1973; Unesco, 1983). The reference level p_r for the calculation is zero dbar. $\Theta = \Theta(S, t, p, 0)$.

5 Speed of sound in m/s calculated after formulation of Chen and Millero (1977).

6 Potential density anomaly (γ_Θ) in kg/m^3. Obtained from the density anomaly γ (ρ - 1000. kg/m^3) at standard atmospheric pressure and replacing the *in situ* temperature with potential temperature (Θ) referenced to standard atmospheric pressure. $\gamma_\Theta = \gamma(S, \Theta, 0)$.

7 *In situ* density anomaly, (γ) in kg/m^3, obtained by computing the density anomaly at measured pressure, temperature, and salinity. $\gamma = \gamma(S, t, p)$.

8 Specific volume anomaly (δ), the specific volume minus that of a Standard Ocean (t = 0°C, S = 35.0, pressure) in units of 10^{-8}m^3/kg.

9 Dynamic depth anomaly (ΔD) in units of dynamic metres (10 m^2/s^2 or 10 J/kg) is the integral of specific volume anomaly with pressure.

10 Potential energy anomaly (χ) in units of 10^5kg/s^2 (10^5J/m^2) is the integral of the specific volume anomaly times pressure, with respect to pressure (by Fofonoff, 1962a).

11 The stability parameter (E) in units of 10^{-8} m^{-1} calculated using the Fofonoff adiabatic levelling method (Bray and Fofonoff, 1981; Millard, Owens and Fofonoff, 1990).

12 Potential temperature gradient in units of 10^{-4} °C/dbar, estimated from the least squares temperature gradient over half the surrounding pressure intervals minus the centre pressure adiabatic lapse rate.

13 Salinity gradient in units of 10^{-4}/dbar. Estimated from the least-squares salinity gradient over half the surrounding pressure intervals.

14 Density ratio, (R_ρ), ie the ratio of temperature and salinity gradients multiplied by the isopycnal derivative $(\partial S/\partial t)_\rho$. See IOT-4, p. 111.

15 Brunt-Väisälä frequency in cph. This calculation uses the adiabatic levelling of steric anomaly (Fofonoff, 1985).

16 The depth (z) in m (Unesco, 1983, pp. 25-28).

Table 2.2 R.V. "Endeavor", cruise 88, station 61. Results of computer processing at standard horizons.

"Endeavor" cruise 88:station 61: 23 August 1982: 1102Z: Lat 36 40.03N: Long 70 59.59W Gravity = 9.7988 m/s^2: Coriolis = 0.87092 x 10^{-4} /s: Sound speed = 1510.4 m/s: Depth = 4200 m															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	25.698	35.221	25.698	1536.3	23.296	23.296	457.24	0	0	0.0	-2.2	0.0	0.00	0.00	0.0
1	25.698	35.221	25.698	1536.3	23.296	23.300	457.28	0.005	0	0.0	-24.3	0.0	0.00	0.00	1.0
10	26.673	36.106	26.671	1539.7	23.658	23.700	423.15	0.043	0	8.4	-0.3	1.0	0.83	0.52	10.0
20	26.678	36.106	26.673	1539.9	23.658	23.742	423.66	0.085	0.1	24.3	-8.0	-0.1	21.26	0.88	19.9
30	26.676	36.107	26.669	1540.0	23.659	23.786	423.98	0.128	0.2	294.2	-42.0	22.1	-0.76	3.08	29.9
50	24.528	36.561	22.517	1535.8	24.670	24.882	328.48	0.204	0.5	3167.0	-911.6	55.9	-6.51	10.09	49.8
75	22.753	36.614	22.738	1531.8	25.236	25.556	275.66	0.278	1.0	1662.1	-570.4	13.8	-15.68	7.31	74.7
100	21.427	36.637	21.407	1528.8	25.630	26.058	239.15	0.342	1.5	728.5	-259.7	3.9	-24.33	4.84	99.6
125	20.633	36.627	20.609	1527.1	25.841	26.378	220.06	0.400	2.2	1091.7	-439.0	-12.3	12.75	5.93	124.4
150	19.522	36.558	19.494	1524.4	26.086	26.732	197.62	0.452	2.9	699.9	-288.5	-7.9	12.52	4.74	149.3
200	18.798	36.555	18.762	1523.2	26.273	27.137	181.67	0.545	4.6	187.0	-86.4	4.2	6.78	2.45	199.0
250	18.431	36.537	18.386	1522.9	26.354	27.435	175.77	0.635	6.6	126.7	-55.7	-1.8	10.30	2.02	248.7
300	18.189	36.526	18.137	1523.0	26.408	27.706	172.46	0.722	9.1	111.7	-55.9	-3.7	4.86	1.90	298.3
400	17.726	36.477	17.657	1523.3	26.489	28.221	168.30	0.892	15.1	62.0	-44.9	-6.5	2.18	1.41	397.6
500	17.165	36.381	17.081	1523.2	26.557	28.724	165.22	1.059	22.8	108.9	-99.4	-17.4	1.82	1.87	496.8
600	15.592	36.105	15.497	1519.7	26.714	29.329	152.33	1.218	31.8	228.7	-219.2	-36.6	1.83	2.71	596.0
700	13.458	35.766	13.357	1514.2	26.914	29.992	134.03	1.361	41.2	210.9	-208.9	-31.0	1.90	2.60	695.1
800	11.109	35.437	11.006	1507.5	27.115	30.668	114.36	1.485	50.7	211.6	-224.6	-29.4	1.94	2.61	794.1
900	8.798	35.178	8.698	1500.5	27.306	31.345	94.60	1.590	59.7	302.8	-258.8	-18.1	3.24	3.12	893.1
1000	6.292	35.044	6.198	1492.4	27.562	32.103	67.07	1.669	67.4	195.9	-162.1	-6.7	4.72	2.51	992.0
1100	5.249	35.004	5.154	1489.9	27.660	32.679	56.70	1.730	73.9	73.4	-63.9	-2.3	4.98	1.54	1090.8
1200	4.813	34.995	4.712	1489.7	27.705	33.187	52.58	1.785	80.3	42.7	-29.4	0.2	-32.27	1.17	1189.6
1300	4.554	34.986	4.446	1490.3	27.727	33.668	50.90	1.836	86.9	24.7	-27.2	-1.7	2.77	0.89	1288.3
1400	4.357	34.977	4.242	1491.2	27.743	34.141	49.89	1.887	93.8	16.3	-13.1	-0.3	8.09	0.72	1387.0
1500	4.245	34.975	4.122	1492.4	27.753	34.605	49.56	1.937	101.2	15.8	-14.1	-0.5	4.56	0.71	1485.6
1750	4.028	34.973	3.884	1495.5	27.777	35.759	49.03	2.060	121.6	13.1	-9.1	0.0	∞	0.65	1732.0
2000	3.852	34.975	3.687	1499.1	27.799	36.906	48.62	2.182	145.0	11.3	-7.7	0.0	∞	0.60	1978.0
2500	3.424	34.968	3.216	1505.7	27.839	39.190	46.92	2.422	200.0	14.1	-10.8	-0.3	5.70	0.67	2469.4
3000	2.963	34.946	2.713	1512.2	27.868	41.453	44.96	2.651	264.3	13.8	-10.8	-0.5	4.34	0.67	2959.6
3500	2.462	34.920	2.170	1518.6	27.894	43.704	41.84	2.867	336.0	10.9	-8.5	-0.5	3.57	0.59	3448.6
4000	2.259	34.904	1.917	1526.3	27.901	45.896	42.02	3.076	415.6	3.8	-3.3	-0.3	1.88	0.35	3936.6
4327	2.221	34.896	1.842	1531.8	27.901	47.304	43.30	3.215	474.7	8.6	-2.3	-0.3	1.08	0.00	4255.2

Table 2.3 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C calibrated on the 1968 International Practical Temperature Scale (IPTS-1968) (Barber 1969).

3 Salinity (S) computed from conductivity (C), temperature and pressure according to the Practical Salinity Scale (1978). (Unesco, 1983, pp. 6-12).

4 Potential temperature (Θ) in °C computed by integrating the adiabatic lapse rate (Bryden, 1973; Unesco, 1983). The reference level p_r for the calculation is zero dbar. $\Theta = \Theta(S, t, p, 0)$.

5 Speed of sound in m/s calculated after formulation of Chen and Millero (1977).

6 Potential density anomaly (γ_Θ) in kg/m^3. Obtained from the density anomaly γ (ρ - 1000. kg/m^3) at standard atmospheric pressure and replacing the *in situ* temperature with potential temperature (Θ) referenced to standard atmospheric pressure. $\gamma_\Theta = \gamma(S, \Theta, 0)$.

7 *In situ* density anomaly, (γ) in kg/m^3, obtained by computing the density anomaly at measured pressure, temperature, and salinity. $\gamma = \gamma(S, t, p)$.

8 Specific volume anomaly (δ), the specific volume minus that of a Standard Ocean (t = 0°C, S = 35.0, pressure) in units of 10^{-8}m^3/kg.

9 Dynamic depth anomaly (ΔD) in units of dynamic metres (10 m^2/s^2 or 10 J/kg) is the integral of specific volume anomaly with pressure.

10 Potential energy anomaly (χ) in units of 10^5kg/s^2 (10^5J/m^2) is the integral of the specific volume anomaly times pressure, with respect to pressure (by Fofonoff, 1962a).

11 The stability parameter (E) in units of 10^{-8} m^{-1} calculated using the Fofonoff adiabatic levelling method (Bray and Fofonoff, 1981; Millard, Owens and Fofonoff, 1990).

12 Potential temperature gradient in units of 10^{-4} °C/dbar, estimated from the least squares temperature gradient over half the surrounding pressure intervals minus the centre pressure adiabatic lapse rate.

13 Salinity gradient in units of 10^{-4}/dbar. Estimated from the least-squares salinity gradient over half the surrounding pressure intervals.

14 Density ratio, R_ρ, i.e., the ratio of temperature and salinity gradients multiplied by the isopycnal derivative $(\partial S/\partial t)_\rho$. See IOT-4, p. 111.

15 Brunt-Väisälä frequency in cph. This calculation uses the adiabatic levelling of steric anomaly (Fofonoff, 1985).

16 The depth (z) in m (Unesco, 1983, pp. 25-28).

Table 2.3 R.V. "Endeavor", cruise 88, station 64. Results of computer processing at standard horizons.

"Endeavor" cruise 88:station 64: 24 August 1982: 0203Z: Lat 37 39.93N: Long 71 00.00W Gravity = 9.7996 m/s^2: Coriolis = 0.89117 x 10^{-4} /s: Sound speed = 1499.8 m/s: Depth = 3892 m															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	26.148	34.646	26.148	1536.7	22.722	22.722	512.09	0.000	0.0	0.0	-2.2	0.0	1.08	0.00	0.0
3	26.148	34.646	26.147	1536.8	22.722	22.735	512.21	0.015	0.0	0.0	-24.6	0.0	1.08	0.00	3.0
10	26.163	34.645	26.161	1536.9	22.717	22.759	513.01	0.051	0.0	4.8	8.9	4.3	1.07	0.39	10.0
20	26.167	34.655	26.163	1537.1	22.724	22.809	512.76	0.103	0.1	4446.3	83.7	636.5	0.06	11.96	20.0
30	25.640	35.733	25.634	1537.2	23.703	23.830	419.82	0.150	0.2	10091.4	-2223.5	460.1	-1.98	18.02	29.9
50	18.967	35.944	18.958	1520.5	25.755	25.971	224.93	0.213	0.5	6187.2	-1095.7	126.9	-5.04	14.11	49.8
75	15.371	35.904	15.360	1510.1	26.590	26.919	146.19	0.258	0.8	1969.9	-808.7	5.1	-46.43	7.96	74.7
100	14.356	35.897	14.341	1507.3	26.809	27.249	126.16	0.291	1.1	536.5	-461.5	-58.6	2.21	4.15	99.5
125	13.059	35.696	13.042	1503.3	26.925	27.479	115.66	0.322	1.4	380.5	-430.5	-64.2	1.77	3.50	124.4
150	12.134	35.567	12.114	1500.4	27.008	27.676	108.20	0.350	1.8	286.7	-263.6	-29.2	2.27	3.04	149.2
200	10.307	35.360	10.283	1494.7	27.185	28.082	92.17	0.400	2.7	300.9	-521.2	-82.2	1.45	3.11	198.8
250	8.783	35.168	8.756	1489.7	27.290	28.419	82.64	0.444	3.7	221.8	-239.8	-21.8	2.30	2.67	248.4
300	8.046	35.117	8.015	1487.7	27.364	28.724	76.16	0.484	4.8	187.2	-157.6	-7.2	4.37	2.45	298.0
400	6.235	35.052	6.199	1482.3	27.568	29.397	57.19	0.550	7.2	172.9	-148.3	-4.4	5.90	2.36	397.2
500	5.230	35.018	5.189	1479.9	27.667	29.963	48.23	0.602	9.6	77.6	-53.7	0.9	-10.05	1.58	496.3
600	5.055	35.044	5.006	1480.9	27.710	30.465	45.29	0.649	12.2	32.5	-20.0	0.9	-3.72	1.02	595.3
700	4.756	35.027	4.700	1481.3	27.731	30.947	44.04	0.694	15.1	22.1	-27.1	-1.6	2.67	0.84	694.3
800	4.399	34.992	4.337	1481.4	27.744	31.423	43.33	0.737	18.5	17.0	-28.9	-2.6	1.78	0.74	793.3
900	4.291	34.991	4.221	1482.6	27.756	31.893	43.11	0.780	22.2	12.3	-7.3	0.4	-2.79	0.63	892.2
1000	4.179	34.986	4.101	1483.8	27.764	32.359	43.12	0.824	26.4	10.8	-10.6	-0.4	4.27	0.59	991.0
1100	4.077	34.982	3.991	1485.0	27.773	32.824	43.07	0.867	31.0	12.2	-17.4	-1.3	2.07	0.63	1089.8
1200	3.969	34.975	3.876	1486.2	27.779	33.287	43.17	0.910	36.1	8.6	-6.4	0.0	-22.07	0.53	1188.6
1300	3.909	34.974	3.807	1487.6	27.786	33.748	43.39	0.953	41.6	9.1	-8.2	-0.2	5.84	0.54	1287.3
1400	3.831	34.973	3.722	1489.0	27.793	34.211	43.36	0.996	47.6	10.0	-7.4	0.0	$-\infty$	0.57	1385.9
1500	3.767	34.975	3.649	1490.4	27.802	34.673	43.26	1.040	54.0	12.3	-7.3	0.3	-3.82	0.63	1484.5
1750	3.600	34.975	3.461	1493.9	27.821	35.823	43.13	1.148	71.9	10.9	-8.8	-0.2	7.64	0.59	1730.9
2000	3.401	34.968	3.242	1497.2	27.837	36.968	42.86	1.256	92.5	11.5	-9.7	-0.3	5.26	0.61	1976.9
2500	2.942	34.948	2.743	1503.7	27.867	39.250	41.39	1.466	140.8	12.5	-10.8	-0.5	3.93	0.63	2468.2
3000	2.475	34.923	2.235	1510.1	27.891	41.515	39.26	1.668	197.3	10.2	-8.7	-0.5	3.45	0.57	2958.3
3500	2.219	34.904	1.933	1517.5	27.900	43.733	39.17	1.863	262.1	3.8	-3.6	-0.3	1.94	0.35	3447.3
3943	2.177	34.896	1.844	1525.0	27.901	45.659	40.98	2.040	329.4	7.0	-1.8	-0.2	0.90	0.00	3879.7

Table 2.4 - Explanation of column headings

1	Pressure (p) in dbar.
2	Temperature (t) in °C calibrated on the 1968 International Practical Temperature Scale (IPTS-1968) (Barber 1969).
3	Salinity (S) computed from conductivity (C), temperature, and pressure according to the Practical Salinity Scale (1978). (Unesco, 1983, pp. 6-12).
4	Potential temperature (Θ) in °C computed by integrating the adiabatic lapse rate (Bryden, 1973; Unesco, 1983). The reference level p_r for the calculation is zero dbar. $\Theta = \Theta(S, t, p, 0)$.
5	Speed of sound in m/s calculated after formulation of Chen and Millero (1977).
6	Potential density anomaly (γ_Θ) in kg/m^3. Obtained from the density anomaly γ (ρ - 1000. kg/m^3) at standard atmospheric pressure and replacing the *in situ* temperature with potential temperature (Θ) referenced to standard atmospheric pressure. $\gamma_\Theta = \gamma(S, \Theta, 0)$.
7	*In situ* density anomaly, (γ) in kg/m^3, obtained by computing the density anomaly at measured pressure, temperature, and salinity. $\gamma = \gamma(S, t, p)$.
8	Specific volume anomaly (δ), the specific volume minus that of a Standard Ocean (t = 0°C, S = 35.0, pressure) in units of 10^{-8}m^3/kg.
9	Dynamic depth anomaly (ΔD) in units of dynamic metres (10 m^2/s^2 or 10 J/kg) is the integral of specific volume anomaly with pressure.
10	Potential energy anomaly (χ) in units of 10^5kg/s^2 (10^5J/m^2) is the integral of the specific volume anomaly times pressure, with respect to pressure (by Fofonoff, 1962a).
11	The stability parameter (E) in units of 10^{-8} m^{-1} calculated using the Fofonoff adiabatic levelling method (Bray and Fofonoff, 1981; Millard, Owens and Fofonoff, 1990).
12	Potential temperature gradient in units of 10^{-4} °C/dbar, estimated from the least squares temperature gradient over half the surrounding pressure intervals minus the centre pressure adiabatic lapse rate.
13	Salinity gradient in units of 10^{-4}/dbar. Estimated from the least-squares salinity gradient over half the surrounding pressure intervals.
14	Density ratio, (R_ρ), i.e., the ratio of temperature and salinity gradients multiplied by the isopycnal derivative $(\partial S/\partial t)_\rho$. See IOT-4, p. 111.
15	Brunt-Väisälä frequency in cph. This calculation uses the adiabatic levelling of steric anomaly (Fofonoff, 1985).
16	The depth (z) in m (Unesco, 1983, pp. 25-28).

Table 2.4 R.V. "Hakuho Maru", cruise KH-87-1, station JT. Results of computer processing at standard horizons.

"Hakuho Maru":cruise KH-87-1:station JT: 28 January 1987: 1230Z: Lat 33 52.90 N: Long 141 55.80 E
Gravity = 9.7964 m/s^2: Coriolis = 0.81304 x 10^{-4} /s: Sound speed = 1517.6 m/s: Depth = 8960 m

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	18.553	34.755	18.553	1517.1	24.948	24.948	299.74	0.000	0.0	0.0	-1.7	0.0	0.00	0.00	0.0
5	18.553	34.755	18.553	1517.2	24.948	24.970	299.90	0.015	0.0	0.0	-19.2	0.0	0.00	0.00	5.0
10	18.640	34.785	18.638	1517.6	24.950	24.933	299.93	0.030	0.0	25.6	88.8	32.6	0.91	0.91	10.0
20	18.643	34.791	18.639	1517.7	24.954	25.040	299.93	0.060	0.1	3.7	-13.0	-3.8	0.98	0.34	19.9
30	18.627	34.789	18.622	1517.9	24.957	25.087	300.02	0.090	0.1	35.1	-24.1	-3.3	2.26	1.06	29.9
50	18.579	34.780	18.570	1518.0	24.963	25.180	300.16	0.150	0.4	20.7	-15.0	-3.3	1.30	0.82	49.8
75	18.564	34.776	18.550	1518.4	24.965	25.290	300.92	0.225	0.9	19.0	-8.8	-0.3	8.88	0.78	74.7
100	18.533	34.772	18.515	1518.7	24.970	25.405	301.28	0.300	1.5	21.8	-10.9	-0.9	3.51	0.84	99.6
125	18.514	34.771	18.493	1519.1	24.975	25.518	301.74	0.376	2.4	19.9	-8.3	-0.2	10.50	0.80	124.5
150	18.490	34.771	18.463	1519.4	24.982	25.633	301.98	0.451	3.5	40.4	-14.4	0.3	-12.21	1.14	149.3
200	18.394	34.769	18.359	1520.0	25.007	25.875	301.42	0.603	6.2	474.2	-156.5	12.0	-4.25	3.91	199.1
250	17.442	34.779	17.400	1518.0	25.250	26.338	279.86	0.746	9.5	370.0	-183.9	-9.5	6.13	3.45	248.8
300	16.826	34.758	16.777	1517.0	25.382	26.690	268.74	0.883	13.3	207.4	-114.1	-8.1	4.36	2.58	298.5
400	15.120	34.640	15.059	1513.3	25.683	27.437	242.50	1.139	22.4	330.9	-196.4	-13.8	4.15	3.26	397.9
500	12.817	34.478	12.749	1507.2	26.039	28.253	209.76	1.366	32.8	403.8	-266.3	-17.4	4.08	3.60	497.2
600	10.184	34.321	10.113	1499.5	26.403	29.089	174.98	1.557	43.5	347.1	-273.2	-18.2	3.52	3.34	596.5
700	7.404	34.127	7.335	1490.6	26.685	29.860	146.40	1.716	54.0	263.7	-257.8	-17.1	3.01	2.91	695.6
800	5.851	34.131	5.781	1486.2	26.894	30.549	125.58	1.850	64.3	185.1	-66.6	12.1	-0.98	2.44	794.7
900	4.778	34.154	4.706	1483.5	27.038	31.169	111.07	1.968	74.5	143.7	-74.6	5.9	-2.12	2.15	893.7
1000	4.092	34.261	4.016	1482.5	27.197	31.799	95.62	2.071	84.5	134.3	-60.2	7.4	-1.31	2.08	992.6
1100	3.693	34.321	3.612	1482.6	27.285	32.353	87.26	2.163	94.2	79.5	-36.7	4.3	-1.32	1.60	1091.5
1200	3.367	34.357	3.280	1482.9	27.346	32.878	81.48	2.247	104.1	69.2	-29.6	4.3	-1.07	1.49	1190.3
1300	3.100	34.402	3.008	1483.5	27.407	33.403	75.72	2.325	114.1	60.1	-23.6	4.0	-0.89	1.39	1289.1
1400	2.880	34.442	2.782	1484.2	27.459	33.917	70.79	2.399	124.2	52.9	-21.9	3.4	-1.00	1.30	1387.8
1500	2.709	34.466	2.605	1485.2	27.494	34.413	67.58	2.468	134.4	37.0	-17.0	2.1	-1.22	1.09	1486.5
1750	2.367	34.529	2.246	1488.0	27.574	35.640	60.20	2.627	160.8	31.3	-12.0	2.1	-0.86	1.00	1733.0
2000	2.149	34.569	2.010	1491.3	27.625	36.829	55.79	2.772	188.4	21.3	-8.7	1.3	-1.01	0.83	1979.1
2500	1.836	34.619	1.658	1498.4	27.693	39.156	50.08	3.034	248.5	13.9	-5.7	0.8	-1.10	0.67	2470.6
3000	1.642	34.653	1.422	1506.1	27.737	41.433	46.75	3.275	316.1	9.1	-3.7	0.5	-1.12	0.54	2960.9
3500	1.556	34.669	1.288	1514.3	27.759	43.661	45.82	3.506	392.7	5.5	-2.2	0.2	-1.01	0.42	3450.1
4000	1.516	34.678	1.196	1522.8	27.774	45.854	45.88	3.735	480.2	3.8	-1.5	0.2	-0.61	0.35	3938.2
4500	1.510	34.685	1.135	1531.4	27.783	48.016	46.66	3.967	580.5	2.5	-1.0	0.1	0.55	0.28	4425.3
5000	1.533	34.688	1.098	1540.3	27.788	50.147	48.07	4.203	695.2	1.5	-0.6	0.1	3.29	0.22	4911.3
5500	1.579	34.689	1.080	1549.2	27.790	52.249	50.07	4.448	826.5	0.6	-0.3	0.0	23.02	0.14	5396.2
6000	1.637	34.690	1.070	1558.2	27.791	54.325	52.39	4.704	976.7	0.3	-0.2	0.0	-∞	0.10	5880.2
6500	1.702	34.689	1.064	1567.3	27.791	56.376	54.97	4.973	1147.8	0.7	-0.1	0.0	-∞	0.00	6363.1
6503	1.703	34.689	1.064	1567.4	27.791	56.388	54.99	4.974	1148.9	0.5	-0.1	0.0	-49.82	0.00	6366.0

Table 2.5 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C (2 decimal places).

3 Salinity (S) (3 decimal places).

4 Specific volume anomaly, $\delta(S, t, 0)$, in units of 10^{-8} m^3/kg for integer values of salinity and one decimal place values of temperature, as given by Table III of IOT-4.

5,6 Temperature and salinity corrections to $\delta(S, t, 0)$ from Tables III(a) and III(b). (The "intermediate" values of "temperature difference", and "salinity difference", second and third lines of Table III, necessary for entering Tables III(a) and III(b), are omitted for the sake of brevity.)

7 Specific volume anomaly at atmospheric pressure, $\delta(S, t, 0)$, appearing as the sum of values in columns 4, 5, and 6.

8,9 Temperature-pressure and salinity-pressure corrections to $\delta(S, t, 0)$, interpolated from Tables V and VI of IOT-4.

10 Specific volume anomaly at given elevated pressure, $\delta(S, t, p)$, the sum of values in columns 7, 8 and 9, in units of 10^{-8} m^3 /kg.

Example of computation of specific volume

Substituting the appropriate values for R.V. "Endeavor" station 61, horizon 1000 dbar (Table 2.5), into formula (5) gives:

$$v(S, t, p) = 0.968224 + 0.000671 = 0.968895 \ (10^3 \ m^3/kg)$$

where the value 0.968224 is taken from Table IV, IOT-4.

Table 2.5 R.V. "Endeavor", cruise 88, station 61. Computation of specific volume anomaly at atmospheric and elevated pressures.

1	2	3	4	5	6	7	8	9	10
0	25.70	35.221	473.2	0	-15.9	457.3	0.0	0	457.3
1	25.70	35.221	473.2	0	-15.9	457.3	0.0	0.0	457.3
10	26.67	36.106	428.1	2.1	-7.6	422.6	0.4	0.0	423.0
20	26.68	36.106	428.1	2.4	-7.6	422.9	0.8	0.1	423.8
30	26.68	36.107	428.1	2.4	-7.7	422.8	1.2	0.1	424.1
50	24.53	36.561	366.1	0.9	-40.4	326.6	2.0	0.2	328.8
75	22.75	36.614	315.7	1.3	-44.4	272.6	2.7	0.3	275.6
100	21.43	36.637	280.8	0.8	-46.1	235.5	3.6	0.3	239.4
125	20.63	36.627	260.0	0.8	-45.5	215.3	4.4	0.4	220.1
150	19.52	36.558	232.2	0.5	-40.5	192.2	5.2	0.5	197.9
200	18.80	36.555	215.1	0.0	-40.4	174.7	6.6	0.5	181.8
250	18.43	36.537	205.4	0.7	-39.0	167.1	8.2	0.6	175.9
300	18.19	36.526	198.3	2.2	-38.3	162.2	9.7	0.7	172.6
400	17.73	36.477	188.9	0.7	-34.7	154.9	12.7	0.9	168.5
500	17.16_5	36.381	175.1	1.5	-27.7	148.9	15.5	1.0	165.4
600	15.59	36.105	139.7	1.9	-7.7	133.9	17.5	1.0	152.4
700	13.46	35.766	170.0	1.1	-56.3	114.8	18.3	0.8	133.9
800	11.11	35.437	127.7	0.2	-32.2_5	95.6_5	18.2	0.5	114.4
900	8.80	35.178	90.5	0.0	-13.2	77.3	17.1	0.2	94.6
1000	6.29	35.044	54.8	1.1	-3.3	52.6	14.4	0.1	67.1
1100	5.25	35.004	43.0	0.6	0.0	43.6	13.0	0.0	56.6
1200	4.81	34.995	113.8	0.1	-74.8	39.1	13.5	0.0	52.6
1300	4.55	34.986	110.6	0.5	-74.2	36.9	13.9	0.0	50.8
1400	4.36	34.977	108.6	0.6	-73.6	35.6	14.3	-0.1	49.8
1500	4.24_5	34.975	107.6	0.4_5	-73.4	34.6_5	14.9	-0.1	49.5
1750	4.03	34.973	105.7	0.3	-73.3	32.7	16.5	-0.1	49.1
2000	3.85	34.975	103.7	0.5	-73.5	30.7	18.0	-0.1	48.6
2500	3.42	34.968	100.0	0.2	-73.1	27.1	19.8	-0.1	46.8
3000	2.96	34.946	95.7	0.5	-71.5	24.7	20.4	-0.3	44.8
3500	2.46	34.920	91.6	0.5	-69.7	22.4	19.7	-0.5	41.6
4000	2.26	34.904	90.1	0.5	-68.5	22.1	20.5	-0.6	42.0
4327	2.22	34.896	90.1	0.2	-67.9	22.4	21.4	-0.6	43.2

Table 2.6 - Explanation of column headings

1	Pressure (p) in dbar.
2	Temperature (t) in °C (2 decimal places).
3	Salinity (S) (3 decimal places).
4	Specific volume anomaly, $\delta(S, t, 0)$, in units of 10^{-8} m^3/kg for integer values of salinity and one decimal place values of temperature, as given by Table III of IOT-4.
5,6	Temperature and salinity corrections to $\delta(S, t, 0)$ from Tables III(a) and III(b). (The "intermediate" values of "temperature difference", and "salinity difference", second and third lines of Table III, necessary for entering Tables III(a) and III(b), are omitted for the sake of brevity.)
7	Specific volume anomaly at atmospheric pressure, $\delta(S, t, 0)$, appearing as the sum of values in columns 4, 5, and 6.
8,9	Temperature-pressure and salinity-pressure corrections to $\delta(S, t, 0)$, interpolated from Tables V and VI of IOT-4.
10	Specific volume anomaly at given elevated pressure, $\delta(S, t, p)$, the sum of values in columns 7, 8 and 9, in units of 10^{-8} m^3 /kg.

Table 2.6 R.V. "Endeavor", cruise 88, station 64. Computation of specific volume anomaly at atmospheric and elevated pressures.

1	2	3	4	5	6	7	8	9	10
0	26.15	34.646	557.2	1.5	-46.6	512.1	0.0	0	512.1
3	26.15	34.646	557.2	1.5	-46.6	512.1	0.1	0.0	512.2
10	26.16	34.645	557.2	1.8	-46.5	512.5	0.4	0.0	512.9
20	26.17	34.655	557.2	2.1	-47.2	512.1	0.8	0.0	512.9
30	25.64	35.733	470.3	1.2	-52.9	418.6	1.2	0.0	419.8
50	18.97	35.944	290.2	1.7	-68.6	223.3	1.7	0.1	225.1
75	15.37	35.904	208.6	1.5	-66.2	143.9	2.3	0.2	146.4
100	14.36	35.897	187.9	1.2	-65.7	123.4	2.8	0.2	126.4
125	13.06	35.696	162.3	1.1	-51.1	112.3	3.2	0.2	115.7
150	12.13	35.567	145.5	0.5	-41.8	104.2	3.7	0.1	108.0
200	10.31	35.360	114.2	0.2	-26.6	87.8	4.4	0.1	92.3
250	8.78	35.168	89.0	1.2	-12.5	77.7	5.6	0.1	83.4
300	8.05	35.117	78.8	0.7	-8.7	70.8	5.4	0.0	76.2
400	6.23_5	35.052	54.8	0.4_5	-3.9	51.3	5.8	0.0	57.1
500	5.23	35.018	43.0	0.3	-1.4	41.9	6.2	0.0	48.1
600	5.05_5	35.044	40.8	0.6_5	-3.3	38.1	7.2	0.0	45.3
700	4.76	35.027	37.5	0.7	-2.1	36.1	7.9	0.0	44.0
800	4.40	34.992	109.6	0.0	-74.6	35.0	8.8	0.0	43.8
900	4.29	34.991	170.6	0.9	-74.6	33.9	9.3	0.0	43.2
1000	4.18	34.986	106.6	0.8	-74.2	33.2	10.0	0.0	43.2
1100	4.08	34.982	105.7	0.8	-74.0	32.5	10.7	0.0	43.2
1200	3.97	34.975	104.7	0.7	-73.5	31.9	11.3	-0.1	43.1
1300	3.91	34.974	104.7	0.1	-73.4	31.4	12.1	-0.1	43.4
1400	3.83	34.973	103.7	0.3	-73.3	30.7	12.8	-0.1	43.4
1500	3.77	34.975	102.8	0.6	-73.5	29.9	12.9	-0.1	42.7
1750	3.60	34.975	101.9	0.0	-73.6	28.3	14.9	-0.1	43.1
2000	3.40	34.968	100.0	0.0	-73.1	26.9	16.0	-0.2	42.7
2500	2.94	34.948	95.7	0.3	-71.7	24.3	17.3	-0.3	41.3
3000	2.47_5	34.923	91.6	0.6	-70.0	22.2	17.2	-0.4	39.0
3500	2.22	34.904	90.1	0.2	-68.5	21.8	17.9	-0.5	39.2
3943	2.18	34.896	89.4	0.6	-68.0	22.0	19.8	-0.5	41.3

Table 2.7 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C (2 decimal places).

3 Salinity (S) (3 decimal places).

4 Specific volume anomaly *in situ*, $\delta(S, t, p)$ (taken from Table 2.5).

5 $\bar{\delta}$, the mean value of $\delta(S, t, p)$ between each two successive levels ($\Delta p = p_n - p_{n-1}$).

6 Dynamic depth anomaly for each layer (ΔD), ($10^{-5}\,\bar{\delta}\,\Delta p$, in dynamic metres). (1 dynamic metre = 10 m^2/s^2 = 10 J/kg - see Sverdrup, Johnson and Fleming (1942), p. 401.)

7 Dynamic depth anomaly from the surface to each level ($\Sigma\Delta D$), in dynamic metres.

8 Values of the quantity $10^{-5}\,\bar{p}\,\bar{\delta}\Delta p$ (product of column 6 and $\bar{p}$, the central pressure of the layer), for each layer.

9 Sum of values of column 8 from above.

10 Potential energy anomaly, χ, in units of 10^5 kg/s^2 ($10^5 J/m^2$) (column 9 divided by local gravity 9.7988 m/s^2 for station 61 and 9.7996 m/s^2 for station 64).

Table 2.7 R.V. "Endeavor", cruise 88, station 61. Computation of dynamic depth and potential energy anomalies.

1	2	3	4	5	6	7	8	9	10
0	25.70	35.221	457.3			0		0.00	0.0
				457.3	0.0046		0		
1	25.70	35.221	457.3			0.0046		0.00	0.0
				440.2	0.0396		0.22		
10	26.67	36.106	423.0			0.0442		0.22	0.0
				423.4	0.0423		0.63		
20	26.68	36.106	423.8			0.0865		0.85	0.1
				424.0	0.0424		1.06		
30	26.68	36.107	424.1			0.1289		1.91	0.2
				376.5	0.0753		3.01		
50	24.53	36.561	328.8			0.2042		4.92	0.5
				302.2	0.0756		4.73		
75	22.75	36.614	275.6			0.2798		9.65	1.0
				257.5	0.0644		5.64		
100	21.43	36.637	239.4			0.3442		15.29	1.6
				229.8	0.0575		6.47		
125	20.63	36.627	220.1			0.4017		21.76	2.2
				209.7	0.0523		7.19		
150	19.52	36.558	197.9			0.4540		28.95	3.0
				189.9	0.0950		16.63		
200	18.80	36.555	181.8			0.5490		45.58	4.7
				178.8	0.0894		20.12		
250	18.43	36.537	175.9			0.6384		65.70	6.7
				174.2	0.0871		23.95		
300	18.19	36.526	172.6			0.7255		89.65	9.2
				170.6	0.1706		59.71		
400	17.73	36.477	168.5			0.8961		149.36	15.2
				167.0	0.1670		75.15		
500	17.16_5	36.381	165.4			1.0631		224.51	22.9
				158.9	0.1589		87.40		
600	15.59	36.105	152.4			1.2220		311.91	31.8
				143.2	0.1432		93.08		
700	13.46	35.766	133.9			1.3652		404.99	41.3
				124.2	0.1242		93.15		
800	11.11	35.437	114.4			1.4894		498.14	50.8
				104.5	0.1045		88.83		
900	8.80	35.178	94.6			1.5939		586.97	59.9
				80.9	0.0809		76.86		
1000	6.29	35.044	67.1			1.6748		663.83	67.7
				61.9	0.0619		65.00		
1100	5.25	35.004	56.6			1.7367		728.83	74.4
				54.6	0.0546		62.79		
1200	4.81	34.995	52.6			1.7913		791.62	80.8
				51.7	0.0517		64.63		
1300	4.55	34.986	50.8			1.8430		856.25	87.4
				50.3	0.0503		67.91		
1400	4.36	34.977	49.8			1.8933		924.16	94.3
				49.7	0.0497		72.06		
1500	4.24_5	34.975	49.5			1.9430		996.22	101.7
				49.3	0.1233		200.36		
1750	4.03	34.973	49.1			2.0663		1196.58	122.1
				48.9	0.1223		229.31		
2000	3.85	34.975	48.6			2.1886		1425.89	145.5
				47.7	0.2385		536.63		
2500	3.42	34.968	46.8			2.4271		1962.52	200.3
				45.8	0.2290		629.75		
3000	2.96	34.946	44.8			2.6561		2592.27	264.6
				43.2	0.2160		702.00		
3500	2.46	34.920	41.8			2.8721		3294.27	336.2
				41.9	0.2090		783.75		
4000	2.26	34.904	42.0			3.0811		4078.02	416.2
				42.6	0.1393		578.10		
4327	2.22	34.896	43.2			3.2204		4656.11	475.1

Table 2.8 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C (2 decimal places).

3 Salinity (S) (3 decimal places).

4 Specific volume anomaly *in situ*, $\delta(S, t, p)$ (taken from Table 2.6).

5 $\bar{\delta}$, the mean value of $\delta(S, t, p)$ between each two successive levels ($\Delta p = p_n - p_{n-1}$).

6 Dynamic depth anomaly for each layer (ΔD), ($10^{-5}\, \bar{\delta}\, \Delta p$, in dynamic metres). (1 dynamic metre = 10 m^2/s^2 = 10 J/kg - see Sverdrup, Johnson and Fleming (1942), p. 401).

7 Dynamic depth anomaly from the surface to each level ($\Sigma\Delta D$), in dynamic metres.

8 Values of the quantity $10^{-5}\, \bar{p}\, \bar{\delta}\Delta p$ (product of column 6 and $\bar{p}$, the central pressure of the layer), for each layer.

9 Sum of values of column 8 from above.

10 Potential energy anomaly, χ, in units of 10^5 kg/s^2 ($10^5 J/m^2$) (column 9 divided by local gravity: 9.7988 m/s^2 for station 61 and 9.7996 m/s^2 for station 64).

Table 2.8 R.V. "Endeavor", cruise 88, station 64. Computation of dynamic depth and potential energy anomalies.

1	2	3	4	5	6	7	8	9	10
0	26.15	34.646	512.1			0		0	0.0
				512.2	0.0154		0.02		
3	26.15	34.646	512.2			0.0154		0.02	0.0
				512.6	0.0359		0.23		
10	26.16	34.645	512.9			0.0513		0.25	0.0
				512.9	0.0513		0.77		
20	26.17	34.655	512.9			0.1026		1.02	0.1
				466.4	0.0466		1.17		
30	25.64	35.733	419.8			0.1492		2.19	0.2
				322.5	0.0645		2.58		
50	18.97	35.944	225.1			0.2137		4.77	0.5
				185.8	0.0465		2.91		
75	15.37	35.904	146.4			0.2602		7.68	0.8
				136.4	0.0341		2.98		
100	14.36	35.897	126.4			0.2943		10.66	1.1
				121.1	0.0303		3.41		
125	13.06	35.696	115.7			0.3246		14.07	1.4
				111.9	0.0280		3.85		
150	12.13	35.567	108.0			0.3526		17.92	1.8
				100.2	0.0501		8.77		
200	10.31	35.360	92.3			0.4027		26.69	2.7
				87.9	0.0440		9.90		
250	8.78	35.168	83.4			0.4467		36.59	3.7
				79.8	0.0399		10.97		
300	8.05	35.117	76.2			0.4866		47.56	4.9
				66.7	0.0667		23.35		
400	6.23_5	35.052	57.1			0.5533		70.91	7.2
				52.6	0.0526		23.67		
500	5.23	35.018	48.1			0.6059		94.58	9.7
				46.7	0.0467		25.69		
600	5.05_5	35.044	45.3			0.6526		120.27	12.3
				44.7	0.0447		29.06		
700	4.76	35.027	44.0			0.6973		149.33	15.2
				43.9	0.0439		32.93		
800	4.40	34.992	43.7			0.7412		182.26	18.6
				43.5	0.0435		36.98		
900	4.29	34.991	43.2			0.7847		219.24	22.4
				43.2	0.0432		41.04		
1000	4.18	34.986	43.2			0.8279		260.28	26.6
				43.2	0.0432		45.36		
1100	4.08	34.982	43.2			0.8711		305.64	31.2
				43.2	0.0432		49.68		
1200	3.97	34.975	43.1			0.9143		355.32	36.3
				43.3	0.0433		54.13		
1300	3.91	34.974	43.4			0.9576		409.45	41.8
				43.4	0.0434		58.59		
1400	3.83	34.973	43.4			1.0010		468.04	47.8
				43.1	0.0431		62.50		
1500	3.77	34.975	42.7			1.0441		530.54	54.1
				42.9	0.1073		174.36		
1750	3.60	34.975	43.1			1.1514		704.90	71.9
				42.9	0.1073		201.19		
2000	3.40	34.968	42.7			1.2587		906.09	92.5
				42.0	0.2100		472.50		
2500	2.94	34.948	41.3			1.4687		1378.59	140.7
				40.2	0.2010		552.75		
3000	2.47_5	34.923	39.0			1.6697		1931.34	197.1
				39.1	0.1955		635.38		
3500	2.22	34.904	39.2			1.8652		2566.72	261.9
				40.3	0.1785		664.38		
3943	2.18	34.896	41.3			2.0437		3231.01	329.7

Table 2.9 - Explanation of column headings

1 Pressure (p) in dbar.

2 Dynamic depth anomaly (ΔD) for each layer for station 61. Taken from column 6 of Table 2.7.

3 Dynamic depth anomaly (ΔD) for station 61 integrated from 2000 dbar (suggested reference level).

4 As for column 2, but for station 64.

5 As for column 3, but for station 64.

6 Dynamic depth anomaly difference between Stations 61 and 64 in dynamic metres (or 10 m^2/s^2).

7 Geostrophic velocity in m/s, calculated from formula (11): values in column 6 are multiplied by a constant factor, 1.0231.

8 Mean value of dynamic depth anomaly difference for successive layers (from column 6).

9 Mean values of volume transport function for successive layers, $\Delta D \Delta z$, in m^3/s^2. When multiplying ΔD by Δz, note that the dimension of one dynamic metre is 10 m^2/s^2.

10 'Potential' (Q) integrated from 2000 dbar.

11 Geostrophic transport between stations 61 and 64 calculated from 2000 dbar in units of 10^6 m^3/s (= 1 Sverdrup) (using formula (13)). Values in column 10 are multiplied by the constant factor 11,350, then divided by 10^6 and rounded to two decimal places.

Table 2.9 R.V. "Endeavor", cruise 88, stations 61 and 64. Computation of geostrophic velocities and transports.

1	2	3	4	5	6	7	8	9	10	11
0		2.1886		1.2587	0.9299	0.951			5197.6	58.99
	0.0442		0.0513				0.9334	93.3		
10		2.1444		1.2074	0.9370	0.959			5104.3	57.93
	0.0423		0.0513				0.9415	94.1		
20		2.1021		1.1561	0.9460	0.968			5010.2	56.87
	0.0424		0.0466				0.9481	94.8		
30		2.0597		1.1095	0.9502	0.972			4915.4	55.79
	0.0753		0.0645				0.9448	188.9		
50		1.9844		1.0450	0.9394	0.961			4726.4	53.64
	0.0756		0.0465				0.9248	231.2		
75		1.9088		0.9985	0.9103	0.931			4495.2	51.02
	0.0674		0.0341				0.8951	223.8		
100		1.8444		0.9644	0.8800	0.900			4271.4	48.48
	0.0575		0.0303				0.8664	216.6		
125		1.7869		0.9341	0.8528	0.872			4054.8	46.02
	0.0523		0.0280				0.8406	210.1		
150		1.7346		0.9061	0.8285	0.848			3844.7	43.64
	0.0950		0.0501				0.8060	402.9		
200		1.6396		0.8560	0.7836	0.802			3441.7	39.07
	0.0893		0.0440				0.7609	380.4		
250		1.5502		0.8120	0.7381	0.755			3061.3	34.75
	0.0870		0.0399				0.7146	357.3		
300		1.4631		0.7721	0.6910	0.707			2704.0	30.69
	0.1706		0.0667				0.6390	639.0		
400		1.2925		0.7054	0.5871	0.601			2065.0	23.44
	0.1670		0.0526				0.5299	529.9		
500		1.1255		0.6528	0.4727	0.484			1535.1	17.42
	0.1589		0.0467				0.4166	416.6		
600		0.9666		0.6061	0.3605	0.369			1118.5	12.69
	0.1432		0.0447				0.3112	311.2		
700		0.8234		0.5614	0.2620	0.268			807.3	9.16
	0.1242		0.0439				0.2218	221.8		
800		0.6992		0.5175	0.1817	0.186			585.5	6.64
	0.1045		0.0435				0.1512	151.2		
900		0.5947		0.4740	0.1207	0.123			434.3	4.93
	0.0809		0.0432				0.1018	101.8		
1000		0.5138		0.4308	0.0830	0.085			332.6	3.77
	0.0619		0.0432				0.0736	73.6		
1100		0.4519		0.3876	0.0643	0.066			258.9	2.94
	0.0546		0.0432				0.0586	58.6		
1200		0.3973		0.3444	0.0529	0.054			200.3	2.27
	0.0517		0.0433				0.0487	48.7		
1300		0.3456		0.3011	0.0445	0.046			151.6	1.72
	0.0503		0.0434				0.0411	41.1		
1400		0.2953		0.2577	0.0376	0.038			110.5	1.25
	0.0497		0.0431				0.0343	34.3		
1500		0.2456		0.2146	0.0310	0.032			76.2	0.86
	0.1233		0.1073				0.0230	57.5		
1750		0.1223		0.1073	0.0150	0.015			18.7	0.21
	0.1223		0.1073				0.0075	18.7		
2000		0.0000		0.0000	0.0000	0.000			00.0	0.00
	0.2385		0.2100				-0.0142	-71.0		
2500		-0.2385		-0.2100	-0.0285	-0.029			-71.0	-0.81
	0.2290		0.2010				-0.0360	-180.0		
3000		-0.4545		-0.4110	-0.0435	-0.045			-251.0	-2.85
	0.2160		0.1955				-0.0537	-268.5		
3500		-0.6705		-0.6065	-0.0640	-0.065			-519.5	-5.90

Table 2.10 - Explanation of column headings

1 Pressure (p) in dbar.

2 Temperature (t) in °C (*in situ*).

3 Salinity (S).

4 Potential temperature Θ_{35}°C (adiabatic cooling); for salinity = 35.0 and reference pressure 0.0. From Table XVIII of IOT-4.

5 Potential temperature correction, $\Delta\Theta_1$°C, to potential temperature (column 4) at temperature and reference pressure of 0.0 for salinities other than 35 and pressure in dbar (salinity-pressure correction). From Table XIX of IOT-4.

6 Potential temperature correction, $\Delta\Theta_2$°C, at a pressure of 10000 dbar and reference pressure 0.0 for given salinity and temperature (temperature-salinity correction). From Table XX of IOT-4 (note that the correction is scaled by $p/10000$ where p = pressure in dbar).

7 Potential temperature, $\Theta = \Theta_{35} + \Delta\Theta_1 + 10^{-4}\, p \cdot \Delta\Theta_2$, the sum of columns 4, 5 and 6 (see IOT-4, p. 114, formula (44)). Values of Θ differ by not more than $2 \cdot 10^{-3}$ °C from computer calculations.

8 Adiabatic temperature adjustment, ΔT_A, at each pressure level. This is the amount by which the temperature decreases adiabatically if a water parcel was raised to the surface. Values obtained by subtracting column 2 from 7 (see formula (16)).

Table 2.10 R.V. "Hakuho Maru", cruise KH-87-1, station JT. Computation of potential temperature (adiabatic cooling during raising to the surface).

1	2	3	4	5	6	7	8
0	18.553	34.755					
100	18.533	34.772	18.515	0.000	0.0	18.515	0.018
200	18.394	34.769	18.360	0.000	0.0	18.360	0.034
300	16.826	34.758	16.773	0.000	0.0	16.773	0.053
400	15.120	34.640	15.059	0.000	0.0	15.059	0.061
500	12.817	34.478	12.747	0.001	0.0	12.748	0.069
600	10.184	34.321	10.112	0.001	0.0	10.113	0.071
700	7.404	34.127	7.334	0.001	0.0	7.335	0.069
800	5.851	34.131	5.780	0.001	0.0	5.781	0.070
900	4.778	34.154	4.705	0.001	0.0	4.706	0.072
1000	4.092	34.261	4.015	0.001	0.0	4.016	0.076
1100	3.693	34.321	3.611	0.001	0.0	3.612	0.081
1200	3.367	34.357	3.279	0.001	0.0	3.280	0.087
1300	3.100	34.402	3.006	0.001	0.0	3.007	0.093
1400	2.880	34.442	2.780	0.001	0.0	2.781	0.099
1500	2.709	34.466	2.603	0.001	0.0	2.604	0.105
1750	2.367	34.529	2.245	0.002	0.0	2.247	0.120
2000	2.149	34.569	2.009	0.002	0.0	2.011	0.138
2500	1.836	34.619	1.657	0.002	0.0	1.659	0.177
3000	1.642	34.653	1.421	0.002	0.0	1.423	0.219
3500	1.556	34.669	1.287	0.002	0.0	1.289	0.267
4000	1.516	34.678	1.195	0.003	0.0	1.198	0.318
4500	1.510	34.685	1.132	0.003	0.0	1.135	0.375
5000	1.533	34.688	1.095	0.003	0.0	1.098	0.435
5500	1.579	34.689	1.077	0.003	0.0	1.080	0.499
6000	1.637	34.690	1.067	0.003	0.0	1.070	0.567
6500	1.702	34.689	1.060	0.003	0.0	1.063	0.639

Table 2.11 - Explanation of column headings

1 Pressure (p) in dbar.

2 Potential temperature, Θ_{35} of sea water of salinity S = 35 and initial temperature 1.063°C at the sea surface (Table 2.10, pressure 6500 dbar, column 7) attained during the process of adiabatic warming from sea surface down to each of the pressure levels. From Table XXI of IOT-4.

3 Potential temperature correction, $\Delta\Theta_1$°C, to potential temperature (column 2) at temperature and reference pressure of 0.0 for salinities other than 35 and pressure in dbar (salinity-pressure correction). From Table XIX of IOT-4 with opposite sign.

4 Potential temperature correction, $\Delta\Theta_2$°C, at a pressure of 10000 dbar and reference pressure 0.0 for given salinity and temperature (temperature-salinity correction). From Table XX of IOT-4 with opposite sign (note that the correction is scaled by $p/10000$ where p = pressure in dbar).

5 Potential temperature, $\Theta' = \Theta_{35} + \Delta\Theta_1 + 10^{-4}\,p \cdot \Delta\Theta_2$, the sum of columns 2, 3, and 4 (see IOT-4, p. 114).

6 Adiabatic temperature adjustment, $\Delta T_A = \Theta' - 1.063$ at each pressure level. This is the amount by which the temperature increases adiabatically if a water parcel was lowered to 6500 dbar, according to formula (16). Compare this column with column 8 of Table 2.10 in the light of the above remarks on "raising-lowering" adiabatic processes.

Table 2.11 R.V. "Hakuho Maru", cruise KH-87-1, station JT. Computation of adiabatic warming during lowering from the surface.

1	2	3	4	5	6
0	1.063				
500	1.088	-0.001	0.0	1.087	0.024
600	1.093	-0.001	0.0	1.092	0.029
700	1.099	-0.001	0.0	1.098	0.035
800	1.104	-0.001	0.0	1.103	0.040
900	1.110	-0.001	0.0	1.109	0.046
1000	1.117	-0.001	0.0	1.116	0.053
1100	1.123	-0.001	0.0	1.122	0.059
1200	1.130	-0.001	0.0	1.129	0.066
1300	1.137	-0.001	0.0	1.136	0.073
1400	1.144	-0.001	0.0	1.143	0.080
1500	1.151	-0.001	0.0	1.150	0.087
1750	1.169	-0.002	0.0	1.167	0.104
2000	1.188	-0.002	0.0	1.186	0.123
2500	1.230	-0.002	0.0	1.228	0.165
3000	1.276	-0.002	0.0	1.274	0.211
3500	1.327	-0.002	0.0	1.325	0.262
4000	1.381	-0.003	0.0	1.378	0.315
4500	1.439	-0.003	0.0	1.436	0.373
5000	1.500	-0.003	0.0	1.497	0.434
5500	1.565	-0.003	0.0	1.562	0.499
6000	1.633	-0.003	0.0	1.630	0.567
6500	1.704	-0.003	0.0	1.701	0.638

Table 2.12 - Explanation of column headings

1 Pressure (p) in dbar.

2 Potential temperature, Θ (from Column 7 of Table 2.10).

3 Salinity (S).

4 Potential temperature, Θ_{35}, of seawater of salinity $S = 35$ and initially at the potential temperature, Θ°C, of each successive pressure level (from column 7, Table 2.10) attained during the process of adiabatic warming from each level down to 6000 dbar. From Table XXI of IOT-4.

5 Potential temperature correction, $\Delta\Theta_1$°C, to potential temperature (column 2) at reference pressure of 0.0 for salinities other than 35 and pressure of 6000 dbar (salinity-pressure-correction). From Table XIX of IOT-4 with opposite sign.

6 Potential temperature correction, $\Delta\Theta_2$°C, at a pressure of 10000 dbar and reference pressure 0.0 for given salinity and temperature (temperature-salinity correction). From Table XX of IOT-4 with opposite sign (note that the correction is scaled by $p/10000$ where p = pressure in dbar).

7 Potential temperature, $\Theta' = \Theta_{35} + \Delta\Theta_1 + 10^{-4}\, p \cdot \Delta\Theta_2$, the sum of values in columns 4, 5 and 6.

8 Adiabatic temperature adjustment, ΔT_A, at each pressure level. This is the amount by which the temperature increases adiabatically if a water parcel was lowered to 6000 dbar from successive pressure horizons. (column 7 - column 2 of Table 2.10).

Note, *inter alia*, that the value at 6000 dbar (1.637°C) is the same as the *in situ* temperature at the same level as in Table 2.10, column 2.

Table 2.12 R.V. "Hakuho Maru", cruise KH-87-1, station JT. Computation of adiabatic warming during lowering from successive standard horizons to 6000 dbar.

1	2	3	4	5	6	7	8
1000	4.016	34.261	4.702	-0.003	0.0	4.699	0.607
1100	3.612	34.321	4.282	-0.003	0.0	4.279	0.586
1200	3.280	34.357	3.937	-0.003	0.0	3.394	0.567
1300	3.007	34.402	3.653	-0.003	0.0	3.650	0.550
1400	2.781	34.442	3.418	-0.003	0.0	3.415	0.535
1500	2.604	34.466	3.235	-0.003	0.0	3.232	0.523
1750	2.247	34.529	2.864	-0.003	0.0	2.861	0.494
2000	2.011	34.569	2.619	-0.003	0.0	2.616	0.467
2500	1.659	34.619	2.253	-0.003	0.0	2.250	0.414
3000	1.423	34.653	2.004	-0.003	0.0	2.001	0.359
3500	1.289	34.669	1.868	-0.003	0.0	1.865	0.309
4000	1.198	34.678	1.772	-0.003	0.0	1.769	0.253
4500	1.135	34.685	1.708	-0.003	0.0	1.705	0.195
5000	1.098	34.688	1.668	-0.003	0.0	1.665	0.132
5500	1.080	34.689	1.650	-0.003	0.0	1.647	0.068
6000	1.070	34.690	1.640	-0.003	0.0	1.637	0.000

Table 2.13 - Explanation of column headings

1	Pressure (p) in dbar.
2,3	Temperature (t) and salinity (S).
4,5	Mean values of temperature and salinity (to enter oceanographic tables and graphs).
6-8	Values according to formula (19), determined from graphs 3(a,b) for column 6, 4(a,b) for column 7 and 5 for column 8 (see pages 90, 92 and 94 respectively).
9	Sum of columns 6, 7, and 8 ($\alpha(S, t, p)$).
10	Vertical temperature gradient (x10^{-4}) (dt/dp).
11-13	Values according to formula (21), determined from graphs 9(a,b) for column 11 and graph 10 for column 12 (see pages 99 and 101 respectively). Column 13 is usually zero (see page 86), and therefore has no graph.
14	Sum of columns 11, 12, and 13 ($\Gamma(S, t, p)$).
15	Column 10 minus column 14 (round brackets in formula (17)) (dt/dp - Γ).
16	Temperature part of stability (the negative product of columns 9 and 15) ($-\alpha(dt/dp) = E_t$)
17-19	Values according to formula (18) determined from graphs 6(a,b) for column 17, 7 for column 18 and 8 for column 19 (see pages 95, 97, and 98 respectively).
20	Sum of columns 17, 18, and 19 (β (S, t, p)).
21	Vertical salinity gradient (x10^{-4}) (dS/dp).
22	Salinity part of stability (the product of columns 20 and 21) (E_s).
23	Total stability (the sum of columns 16 and 22) (E).

Note: The values of columns 16, 22, and 23 are in units of 10^{-8} m^{-1}.

Table 2.13 R.V."Hakuho Maru", KH-87-1, station JT. Computation of vertical stability by Hesselberg-Sverdrup's method.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
0	18.553	34.755	18.6	34.8	2.45	-	-	2.45	87	1.75	-	-	1.8	85	-208.2	7.46	-	-	7.46	30	223.8	15.6
10	18.640	34.785	18.6	34.8	2.45	-	-	2.45	3.0	1.75	-	-	1.8	1.2	2.9	7.46	-	-	7.46	6	44.8	41.9
20	18.643	34.791	18.6	34.8	2.45	-	-	2.45	-16	1.75	-	-	1.8	-18	44.1	7.46	-	-	7.46	-2	-14.9	29.2
30	18.627	34.789	18.6	34.8	2.45	-	-	2.45	-24	1.75	-	-	1.8	-26	63.7	7.46	-	-	7.46	-4.5	-33.6	30.1
50	18.579	34.780	18.6	34.8	2.45	0.01	-	2.46	-6.0	1.75	0.01	-	1.8	-7.8	19.2	7.46	-0.01	-	7.45	-1.6	-11.9	7.3
75	18.564	34.776	18.5	34.8	2.45	0.01	-	2.46	-4.4	1.74	0.01	-	1.8	-6.2	15.2	7.46	-0.01	-	7.45	-1.6	-11.9	3.3
100	18.553	34.772	18.5	34.8	2.45	0.01	-	2.46	-15.6	1.74	0.01	-	1.8	-17.4	42.8	7.46	-0.01	-	7.45	-0.4	-3.0	39.8
125	18.514	34.771	18.5	34.8	2.45	0.02	-	2.47	-9.6	1.74	0.01	-	1.8	-11.4	28.2	7.46	-0.01	-	7.45	0	0	28.2
150	18.490	34.771	18.4	34.8	2.44	0.02	-	2.46	-19	1.74	0.02	-	1.8	-21	51.7	7.46	-0.02	-	7.45	-0.4	-3.0	48.7
200	18.394	34.769	17.9	34.8	2.39	0.03	-	2.42	-190	1.70	0.02	-	1.7	-192	464.6	7.47	-0.03	0.01	7.45	2.0	14.9	479.5
250	17.442	34.779	17.1	34.8	2.32	0.04	-	2.36	-123	1.65	0.03	-	1.7	-125	295	7.48	-0.03	0.01	7.46	-4.2	-31.3	263.7
300	16.826	34.758	16.0	34.7	2.23	0.05	-	2.28	-171	1.57	0.03	-	1.6	-173	394.4	7.50	-0.04	0.01	7.47	-11.8	-88.1	306.3
400	15.120	34.640	14.0	34.6	2.04	0.07	-	2.11	-230	1.43	0.05	-	1.5	-232	489.5	7.53	-0.05	0.01	7.49	-16.2	-121.3	368.2
500	12.817	34.478	11.5	34.4	1.81	0.09	-	1.90	-263	1.25	0.07	-	1.3	-264	501.6	7.58	-0.06	0.01	7.53	-15.7	-118.2	383.4
600	10.814	34.321	8.8	34.2	1.53	0.12	-	1.65	-278	1.06	0.09	-	1.2	-279	460.4	7.63	-0.08	0.01	7.56	-19.4	-146.7	313.7
700	7.404	34.127	6.6	34.1	1.30	0.15	-	1.45	-155	0.89	0.11	-	1.0	-156	226.2	7.68	-0.09	0.01	7.60	0.4	3.0	229.2
800	5.851	34.131	5.3	34.1	1.15	0.18	-	1.33	-107	0.78	0.13	-	0.9	-108	143.6	7.71	-0.10	0.01	7.62	2.3	17.5	161.1
900	4.778	34.154	4.4	34.2	1.04	0.21	-	1.25	-69	0.71	0.15	-	0.9	-70	87.5	7.73	-0.11	0.01	7.63	10.7	81.6	169.1
1000	4.092	34.261	3.9	34.3	0.99	0.24	-	1.23	-40	0.67	0.17	-	0.8	-41	50.4	7.75	-0.12	0.01	7.64	6.0	45.8	96.2
1100	3.693	34.321	3.5	34.3	0.94	0.27	-	1.21	-33	0.64	0.18	-	0.8	-34	41.1	7.76	-0.13	0.01	7.64	3.6	27.5	68.6
1200	3.367	34.357	3.2	34.4	0.91	0.30	-	1.21	-27	0.61	0.20	-	0.8	-28	33.9	7.76	-0.15	0.01	7.62	4.5	34.3	68.2
1300	3.100	34.402	3.0	34.4	0.89	0.32	-	1.21	-22	0.60	0.22	-	0.8	-23	27.8	7.77	-0.16	0.01	7.62	4.0	30.5	58.3
1400	2.880	34.442	2.8	34.5	0.87	0.35	-	1.22	-17	0.58	0.24	-	0.8	-18	22.0	7.78	-0.17	0.01	7.62	0.4	3.1	25.1
1500	2.709	34.446	2.5	34.5	0.82	0.39	-	1.21	-13.7	0.56	0.27	-	0.8	-14.5	17.5	7.78	-0.19	0.01	7.60	3.32	25.3	42.7
1750	2.367	34.529	2.3	34.5	0.80	0.45	-	1.25	-8.7	0.54	0.31	-	0.8	-9.5	11.9	7.79	-0.22	0.01	7.58	1.60	12.1	24.0
2000	2.149	34.569	2.0	34.6	0.77	0.55	-	1.32	-6.3	0.52	0.37	-	0.9	-7.2	9.5	7.80	-0.26	0.01	7.55	1.00	7.6	17.6
2500	1.836	34.619	1.7	34.6	0.74	0.66	-	1.40	-3.9	0.49	0.45	-	0.9	-4.8	6.7	7.80	-0.31	0.01	7.50	0.68	5.1	11.8
3000	1.642	34.653	1.6	34.7	0.72	0.78	-	1.50	-1.7	0.48	0.53	-	1.0	-2.7	4.0	7.81	-0.36	0.01	7.46	0.32	2.4	6.4
3500	1.556	34.669	1.5	34.7	0.71	0.90	-	1.61	-0.8	0.48	0.61	-	1.1	-1.9	3.1	7.81	-0.42	0.01	7.40	0.18	1.3	4.4
4000	1.516	34.678	1.5	34.7	0.71	1.00	-	1.71	-0.1	0.48	0.68	-	1.2	-1.3	2.2	7.81	-0.46	0.01	7.36	0.14	1.0	3.2
4500	1.510	34.685	1.5	34.7	1.71	1.10	-	1.81	0.5	0.48	0.75	-	1.3	-0.8	1.4	7.81	-0.51	0.01	7.31	0.06	0.4	1.8
5000	1.533	34.688	1.6	34.7	0.72	1.20	-	1.92	0.9	0.48	0.82	-	1.3	-0.4	0.8	7.81	-0.56	0.02	7.27	0.02	0.1	0.9
5500	1.579	34.689	1.6	34.7	0.72	1.29	-	2.01	1.2	0.48	0.88	-	1.4	-0.2	0.4	7.81	-0.61	0.02	7.22	0.02	0.1	0.5
6000	1.637	34.690	1.7	34.7	0.74	1.38	-	2.12	1.3	0.49	0.94	-	1.4	-0.1	0.2	7.80	-0.66	0.02	7.16	-0.02	-0.1	0.1
6500	1.702	34.689																				

Table 2.14 - Explanation of column headings

1	Pressure (p) in dbar.
2,3	Temperature (t) and salinity (S).
4	Temperature part of stability, E_t (from column 16 of Table 2.13*).
5	Salinity part of stability, E_S (from column 22 of Table 2.13*).
6	Total stability, $E = E_t + E_S$ (from column 23 of Table 2.13*)
7	Density ratio, $R_\rho = E_t/E_S$ (i.e. column 4/column 5) - dimensionless.
8	Brunt-Väisälä frequency, $\sqrt{gE}$ (in units of $10^{-3}s^{-1}$).
9	Potential vorticity, fE (in units of $10^{-11}m^{-1}s^{-1}$).

Note: In order to convert the frequency in units of s^{-1} (as shown in this table) to units of cph (as shown in Tables 2.2-2.4), the values in column 8 should be multiplied by the scaling factor $3600/2\pi \approx 0.573 \cdot 10^3$.

* Refers only to R.V. "Hakuho Maru" station JT. Similar stability derivations for the two R.V. "Endeavor" stations have not been included.

Table 2.14 R.V. "Endeavor", cruise 88, station 61. Computation of density ratio, Brunt-Väisälä frequency and potential vorticity.

1	2	3	4	5	6	7	8	9
0	25.698	35.221	-2987	6522	3535	0.46	18.61	307.87
10	26.673	36.106	-8.4	0	-8.4	-	-	-
20	26.678	36.106	13.3	7.4	20.7	-1.80	1.42	1.80
30	26.676	36.107	3250	1673	4923	-1.94	21.96	428.75
50	24.528	36.561	2058	156	2214	-13.19	14.73	192.82
75	22.753	36.614	1474	68	1542	-21.68	12.29	134.30
100	21.427	36.637	858	-30	828	28.60	9.01	72.11
125	20.633	36.627	1164	-205	959	5.68	9.69	83.52
150	19.522	36.558	375	-4.5	371	83.33	6.03	32.31
200	18.798	36.555	188	-27	161	6.96	3.97	14.02
250	18.431	36.537	124	-16	108	7.75	3.25	9.41
300	18.189	36.526	119	-36	83	3.31	2.85	7.23
400	17.726	36.477	142	-71	71	2.00	2.64	6.18
500	17.165	36.381	375	-205	170	1.83	4.08	14.81
600	15.592	36.105	473	-253	220	1.87	4.64	19.16
700	13.458	35.766	474	-246	228	1.93	4.73	19.86
800	11.109	35.437	418	-195	223	2.14	4.67	19.42
900	8.798	35.178	403	-101	302	3.99	5.44	26.30
1000	6.292	35.044	152	-30	122	5.07	3.46	10.63
1100	5.249	35.004	63	-6.8	56	9.26	2.34	4.88
1200	4.813	34.995	37	-6.8	30	5.44	1.71	2.61
1300	4.554	34.986	29	-6.8	22.2	4.26	1.47	1.93
1400	4.357	34.977	16.6	-1.5	15.1	11.07	1.22	1.32
1500	4.245	34.975	13.5	-0.8	12.7	16.88	1.12	1.11
1750	4.028	34.973	11.4	0.8	12.2	-14.25	1.09	1.06
2000	3.852	34.975	14.1	-1.1	13.0	12.82	1.13	1.13
2500	3.424	34.968	15.8	-3.3	12.5	4.79	1.11	1.09
3000	2.963	34.946	18.0	-3.9	14.1	4.62	1.18	1.23
3500	2.462	34.920	8.7	-2.4	6.3	3.62	0.79	0.55
4000	2.259	34.904	3.5	-1.8	1.7	1.94	0.41	0.15
4327	2.221	34.896						

Table 2.15 - Explanation of column headings

1	Pressure (p) in decibars.
2,3	Temperature (t) and salinity (S).
4	Temperature part of stability, E_t (from column 16 of Table 2.13*).
5	Salinity part of stability, E_S (from column 22 of Table 2.13*).
6	Total stability, $E = E_t + E_S$ (from column 23 of Table 2.13*)
7	Density ratio, $R_\rho = E_t/E_S$ (i.e. column 4/column 5) - dimensionless.
8	Brunt-Väisälä frequency, $\sqrt{gE}$ (in units of $10^{-3}s^{-1}$)
9	Potential vorticity, fE (in units of $10^{-11}m^{-1}s^{-1}$).

Note: In order to convert the frequency in units of s^{-1} (as shown in this table) to units of cph (as shown in Tables 2.2-2.4), the values in column 8 should be multiplied by the scaling factor $3600/2\pi \approx 0.573 \cdot 10^3$.

* Refers only to R.V. "Hakuho Maru" station JT. Similar stability derivations for the two R.V. "Endeavor" stations have not been included.

Table 2.15 R.V. "Endeavor", cruise 88, station 64. Computation of density ratio, Brunt-Väisälä frequency and potential vorticity.

1	2	3	4	5	6	7	8	9
0	26.148	34.646						
			-40	-7.4	-47	5.40	-	-4.19
10	26.163	34.645						
			-5.5	74	68	0.07	2.58	6.06
20	26.167	34.655						
			1608	7945	9553	-0.20	30.60	851.33
30	25.640	35.733						
			9246	787	10033	-11.75	31.35	894.11
50	18.967	35.944						
			3384	-120	3264	28.20	17.88	290.88
75	15.371	35.904						
			877	-21	856	41.76	9.16	76.28
100	14.356	35.897						
			1061	-602	459	1.76	6.71	40.90
125	13.059	35.696						
			720	-393	327	1.83	5.66	29.14
150	12.134	35.567						
			670	-310	360	2.16	5.94	32.08
200	10.307	35.360						
			508	-288	220	1.76	4.64	19.61
250	8.783	35.168						
			231	-76	155	3.04	3.90	13.81
300	8.406	35.117						
			262	-50	212	5.24	4.56	18.89
400	6.235	35.052						
			133	-26	107	5.12	3.24	9.54
500	5.230	35.018						
			24	20	44	1.20	2.08	3.92
600	5.055	35.044						
			39	-13	26	3.00	1.60	2.32
700	4.756	35.027						
			46	-27	19	1.70	1.36	1.69
800	4.399	34.992						
			15	-0.8	14	18.75	1.17	1.25
900	4.291	34.991						
			15	-3.8	11	3.95	1.04	0.98
1000	4.179	34.986						
			14	-3.1	11	4.52	1.04	0.98
1100	4.077	34.982						
			15	-5.3	10	2.83	0.99	0.89
1200	3.969	34.975						
			8.9	-0.8	8.1	11.12	0.89	0.72
1300	3.909	34.974						
			11	-0.8	11	13.75	1.04	0.98
1400	3.831	34.973						
			9.8	1.5	11	-6.53	1.04	0.98
1500	3.767	34.975						
			10	0.0	10	-	0.99	0.89
1750	3.600	34.975						
			12	-2.3	10	5.22	0.99	0.89
2000	3.401	34.968						
			15	-3.0	12	5.00	1.08	1.07
2500	2.942	34.948						
			16	-3.7	12	4.32	1.08	1.07
3000	2.475	34.923						
			9.6	-3.0	6.6	3.20	0.80	0.59
3500	2.219	34.904						
			3.3	-1.5	1.8	2.20	0.42	0.16
3943	2.177	34.896						

Table 2.16 - Explanation of column headings

1	Pressure (p) in dbar.
2,3	Temperature (t) and salinity.
4	Temperature part of stability, E_t (from column 16 of Table 2.13*).
5	Salinity part of stability, E_S (from column 22 of Table 2.13*).
6	Total stability, $E = E_t + E_S$ (from column 23 of Table 2.13*)
7	Density ratio, $R_\rho = E_t/E_S$ (i.e. column 4/column 5) - dimensionless.
8	Brunt-Väisälä frequency, $\sqrt{gE}$ (in units of $10^{-3}s^{-1}$)
9	Potential vorticity, fE (in units of $10^{-11}m^{-1}s^{-1}$).

Note: In order to convert the frequency in units of s^{-1} (as shown in this table) to units of cph (as shown in Tables 2.2-2.4), the values in column 8 should be multiplied by the scaling factor $3600/2\pi \approx 0.573 \cdot 10^3$.

* Refers only to R.V. "Hakuho Maru" station JT. Similar stability derivations for the two R.V. "Endeavor" stations have not been included.

Table 2.16 RV "Hakuho Maru", cruise KH-87-1, station JT. Computation of density ratio, Brunt-Väisälä frequency and potential vorticity.

1	2	3	4	5	6	7	8	9
0	18.553	34.755						
			-208.2	223.8	15.6	0.93	-1.24	1.27
10	18.640	34.785						
			2.9	44.8	47.7	-0.06	2.03	3.41
20	18.643	34.791						
			44.1	-14.9	29.2	2.96	1.69	2.37
30	18.627	34.789						
			63.7	-33.6	30.1	1.90	1.72	2.45
50	18.579	34.780						
			19.2	-11.9	7.3	16.13	0.85	0.59
75	18.564	34.776						
			15.2	-11.9	3.3	5.07	0.57	0.27
100	18.533	34.772						
			42.8	-3.0	39.8	14.27	1.40	3.24
125	18.514	34.771						
			28.2	0.0	28.2	-	1.66	2.29
150	18.490	34.771						
			51.7	-3.0	48.7	17.23	2.18	3.96
200	18.394	34.769						
			464.6	14.9	479.5	-31.18	6.85	38.99
250	17.442	34.779						
			295	-31.3	263.7	9.42	5.08	21.44
300	16.826	34.758						
			394.4	-88.1	306.3	4.48	5.48	24.90
400	15.120	34.640						
			489.5	-121.3	368.2	4.04	6.01	29.94
500	12.817	34.478						
			501.6	-118.2	383.4	4.24	6.13	31.17
600	10.184	34.321						
			460.4	-146.7	313.7	3.14	5.54	25.51
700	7.404	34.127						
			226.2	3.0	229.2	-75.40	4.74	18.63
800	5.851	34.131						
			143.6	17.5	161.1	-8.21	3.97	13.10
900	4.778	34.154						
			87.5	81.6	169.1	-1.07	4.07	13.75
1000	4.092	34.261						
			50.4	45.8	96.2	-1.10	3.07	7.82
1100	3.693	34.321						
			41.1	27.5	68.6	-1.49	2.59	5.58
1200	3.367	34.357						
			33.9	34.3	68.2	-0.99	2.58	5.54
1300	3.100	34.402						
			27.8	30.5	58.3	-0.91	2.39	4.74
1400	2.880	34.442						
			22.0	3.1	25.1	-7.21	1.57	2.04
1500	2.709	34.446						
			17.5	25.2	42.7	-0.69	2.05	3.47
1750	2.367	34.529						
			11.9	12.1	24.0	-0.98	1.53	1.95
2000	2.149	34.569						
			9.5	7.6	17.1	-1.25	1.29	1.39
2500	1.836	34.619						
			6.7	5.1	11.8	-1.31	1.08	0.96
3000	1.642	34.653						
			4.0	2.4	6.4	-1.67	0.79	0.52
3500	1.556	34.669						
			3.1	1.3	4.4	-2.38	0.66	0.36
4000	1.516	34.678						
			2.2	1.0	3.2	-2.20	0.56	0.26
4500	1.510	34.685						
			1.4	0.4	1.8	-3.50	0.42	0.15
5000	1.533	34.688						
			0.8	0.1	0.9	-8.00	0.31	0.07
5500	1.579	34.689						
			0.4	0.1	0.5	-4.00	0.22	0.04
6000	1.637	34.690						
			0.2	-0.1	0.1	2.00	0.10	0.01
6500	1.702	34.689						

Table 2.17 Depth-to-pressure conversion at various latitudes.

Depth	Latitude (°)						
	0	15	30	45	60	75	90
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
500	503.37	503.55	504.04	504.71	505.37	505.87	506.04
1000	1007.96	1008.32	1009.30	1010.64	1011.98	1012.96	1013.32
1500	1513.76	1514.30	1515.77	1517.78	1519.80	1521.27	1521.82
2000	2020.76	2021.48	2023.44	2026.13	2028.82	2030.80	2031.52
2500	2528.95	2529.85	2532.31	2535.68	2539.05	2541.53	2542.43
3000	3038.31	3039.40	3042.36	3046.41	3050.47	3053.44	3054.53
3500	3548.85	3550.12	3553.58	3558.32	3563.06	3566.54	3567.82
4000	4060.55	4062.00	4065.97	4071.39	4076.83	4080.82	4082.28
4500	4573.41	4575.04	4579.51	4585.62	4591.75	4596.25	4597.89
5000	5087.40	5089.22	5094.19	5101.01	5107.83	5112.84	5114.67
5500	5602.54	5604.54	5610.03	5617.53	5625.06	5630.57	5632.59
6000	6118.79	6120.98	6126.98	6135.18	6143.40	6149.44	6151.65
6500	6636.16	6638.54	6645.05	6653.96	6662.89	6669.44	6671.84
7000	7154.64	7157.21	7164.23	7173.85	7183.48	7190.55	7193.13
7500	7674.21	7676.97	7684.51	7694.84	7705.18	7712.77	7715.55
8000	8194.88	8197.83	8205.89	8216.91	8227.99	8236.10	8239.05
8500	8716.64	8719.77	8728.35	8740.07	8751.88	8760.51	8763.64
9000	9239.46	9242.77	9251.87	9264.34	9276.84	9285.99	9289.34
9500	9763.35	9766.83	9776.46	9789.66	9802.86	9812.54	9816.11
10000	10288.28	10291.96	10302.12	10316.03	10329.96	10340.18	10343.93

Part 3. Oceanographic graphs

Twelve graphs have been included in the following pages. The purpose of including them here is to provide an alternative to the use of the IOT-4 tables at a similar level of precision. These graphs also provide a useful purpose in depicting the behaviour of the various functions of the equation of state of seawater.

The graphs are:

Graph nos	Description	Page(s)
1(a,b)	Temperature-pressure correction, $10^8\delta(t, p)$ (m^3/kg) to specific volume (or anomaly of specific volume).	87-88
2	Salinity-pressure correction, $10^8\delta(S, p)$ (m^3/kg) to specific volume (or anomaly of specific volume).	89
3(a,b)	Coefficient of thermal expansion at atmospheric pressure, $10^4\alpha(S, t, 0) = -10^4(1/\rho)(\partial\rho/\partial t)$.	90-91
4(a,b)	Temperature-pressure correction, $-10^4\ \Delta\alpha'(t, p)$, to coefficient of thermal expansion, $10^4\alpha(S, t, 0)$.	92-93
5	Salinity-pressure correction, $-10^4\ \Delta\alpha(S, p)$, to coefficient of thermal expansion, $10^4\ \alpha(S, t, 0)$.	94
6(a,b)	Coefficient of salinity contraction at atmospheric pressure, $10^4\ \beta(S, t, 0) = 10^4(1/\rho)(\partial\rho/\partial S)$.	95-96
7	Salinity-pressure correction, $10^4\Delta\beta'(S, p)$, to coefficient of saline contraction, $10^4\beta(S, t, 0)$.	97
8	Temperature-pressure correction, $10^4\Delta\beta(t, p)$, to coefficient of saline contraction, $10^4\beta(S, t, 0)$.	98
9(a,b)	Adiabatic temperature gradient at atmospheric pressure, $10^4\ \Gamma(S, t, 0)$.	99-100
10	Temperature-pressure correction, $10^4\Delta\Gamma'(t, p)$, to adiabatic temperature gradient, $10^4\Gamma(S, t, 0)$	101
11	Speed of sound as function of temperature and pressure at constant salinity $S = 35$.	102
12	Speed of sound correction for salinity.	103

Graphs 1, 2, 3, 6 and 9 repeat in graphical form Tables V, VI, VII, IX and XVI of IOT-4 respectively. The other graphs (for corrections) have been produced from tables published in (Mamayev and Arkhipkin, 1987). Graphs 11 and 12 are based on (Anon. 1962) but are here redrawn in order to take into account EOS-80.

The "correction" graphs are based on Taylor's series expansion of the given function. For example, in the case of the thermal expansibility coefficient:

$$\alpha(S, t, p) = \alpha(S, t, 0) + \Delta\alpha(p) + \Delta\alpha(t, p) + \Delta\alpha(S, p) + \ldots.$$

where

$$\Delta\alpha(p) = \alpha(35, 0, p) - \alpha(35, 0, 0)$$

$$\Delta\alpha(t, p) = (\alpha(35, t, p) - \alpha(35, 0, 0)) - (\alpha(35, t, 0) - \alpha(35, 0, 0))$$

$$\Delta\alpha(S, p) = (\alpha(S, 0, p) - \alpha(35, 0, p)) - (\alpha(S, 0, 0) - \alpha(35, 0, 0))$$

Combining into one correction second and third terms of the right-hand expression in (I) for thermal expansibility and adiabatic lapse rate and second and fourth terms for salinity "contraction", we obtain

$$\Delta\alpha'(t, p) = \alpha(35, t, p) - \alpha(35, t, 0)$$

$$\Delta\Gamma'(t, p) = \Gamma(35, t, p) - \Gamma(35, t, 0)$$

$$\Delta\beta'(S, p) = \beta(S, 0, p) - \beta(S, 0, 0)$$

(this procedure was first employed by Fofonoff (1962b). Thus, final formulas for the computation of the values *in situ* are:

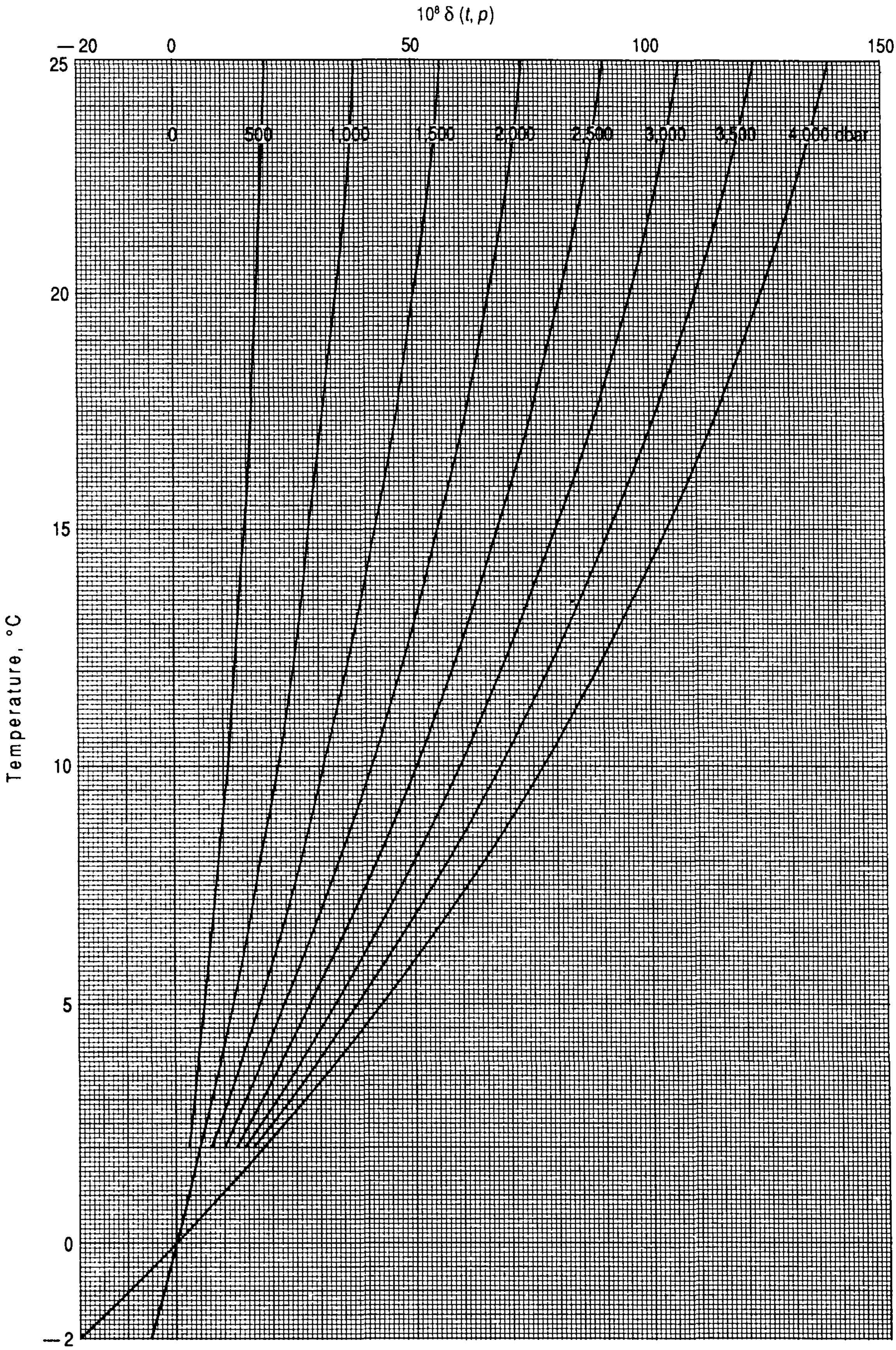
$$\alpha(S, t, p) = \alpha(S, t, 0) + \Delta\alpha'(t, p) + \Delta\alpha(S, p)$$

$$\beta(S, t, p) = \beta(S, t, 0) + \Delta\beta'(S, p) + \Delta\beta(t, p)$$

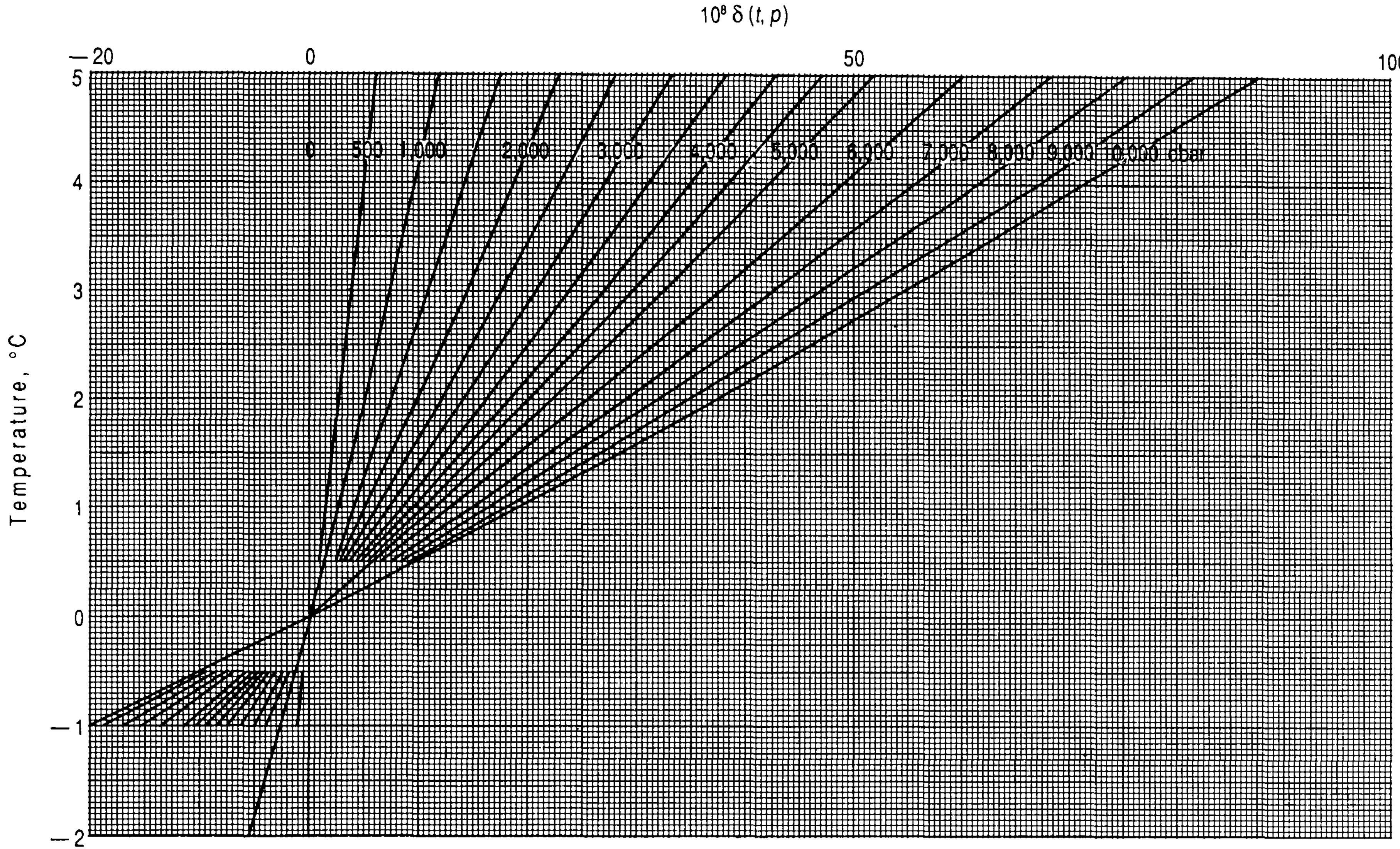
$$\Gamma(S, t, p) = \Gamma(S, t, 0) + \Delta\Gamma'(t, p) + \Delta\Gamma(S, p)$$

for thermal expansibility, saline "contraction" and adibatic lapse rate. It should be noted that the graph for $\Delta\Gamma(S, p)$ is not given, this correction being negligible in oceanic ranges of temperature, salinity and pressure.

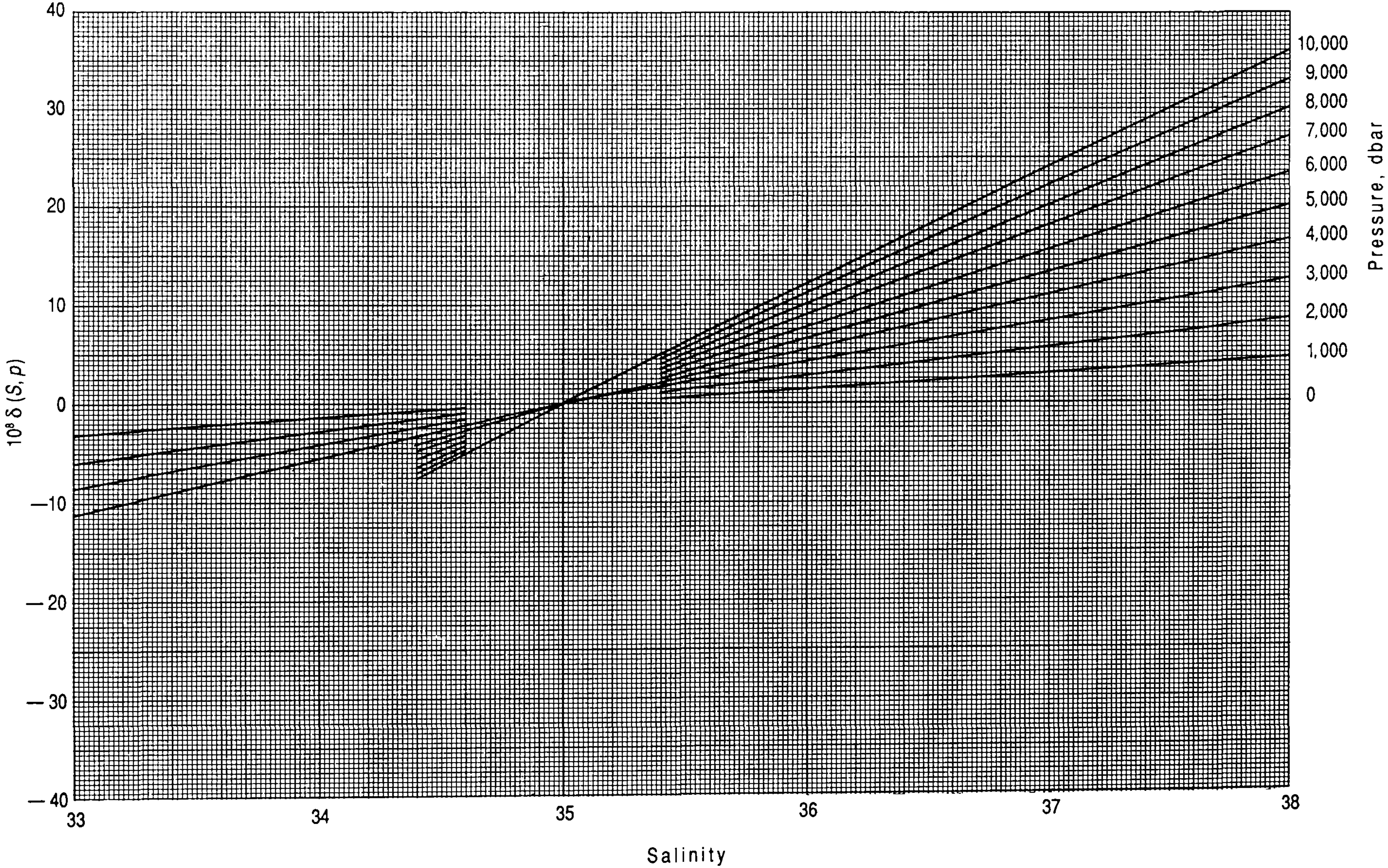
If temperature and salinity values are given accurate to 10^{-2} (two decimal places), then the corresponding functions can also be determined with a precision of 10^{-2} in the values of α, β and Γ multiplied by 10^4, as traditionally used in oceanography. Errors due to pressure interpolation are negligible. The reader can test this by comparing the values computed in Part 2 of this Manual with those obtained from these graphs. It will be clear that these graphs provide an equally accurate means for determining the properties of seawater, as do the Tables of IOT-4. It also can be seen from some of the graphs that they provide even better precision, i.e. 10^{-3}.



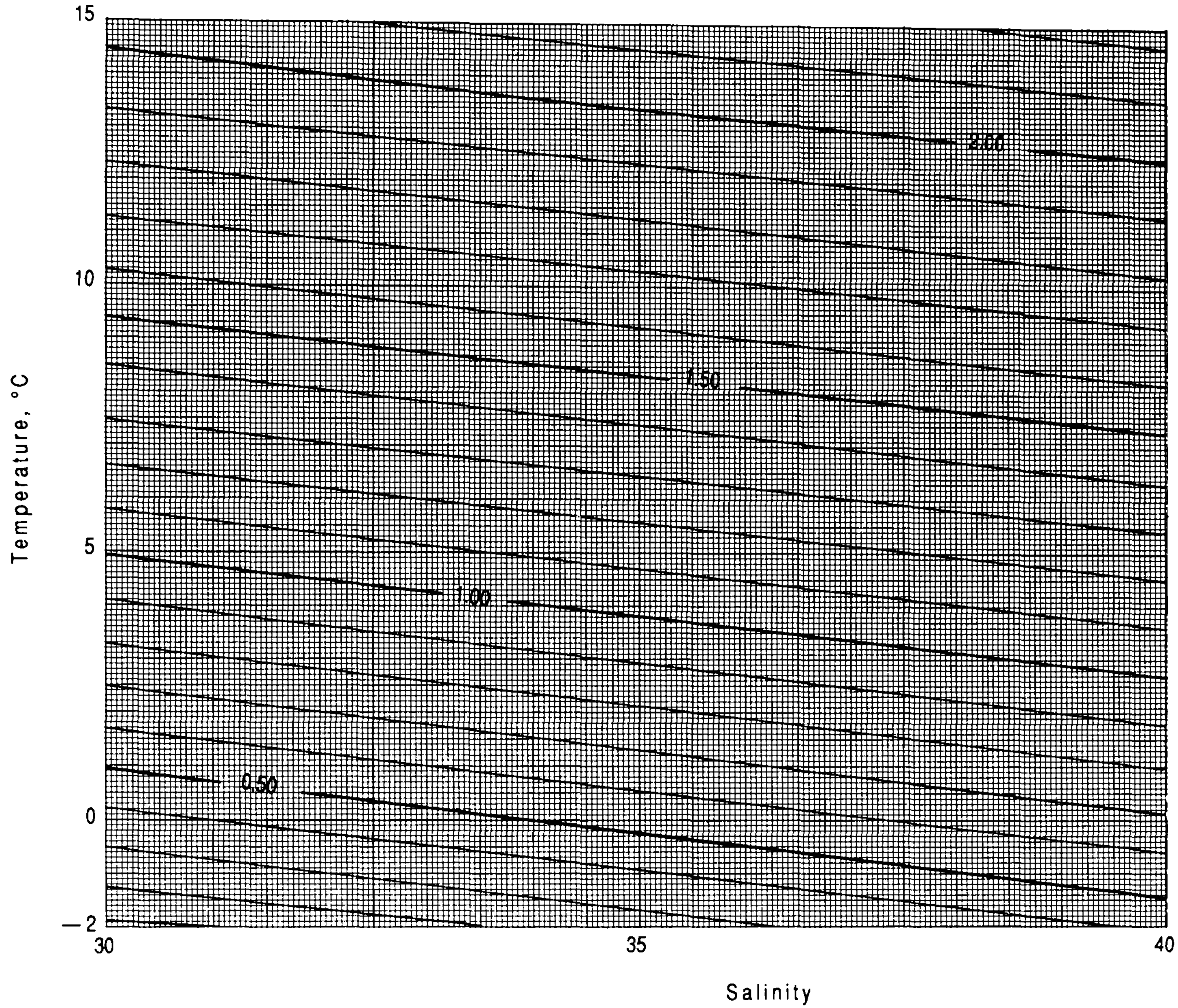
Graph 1a Temperature-pressure correction, $10^8\delta(t,\ p)$ (m^3/kg) to specific volume (or anomaly of specific volume).



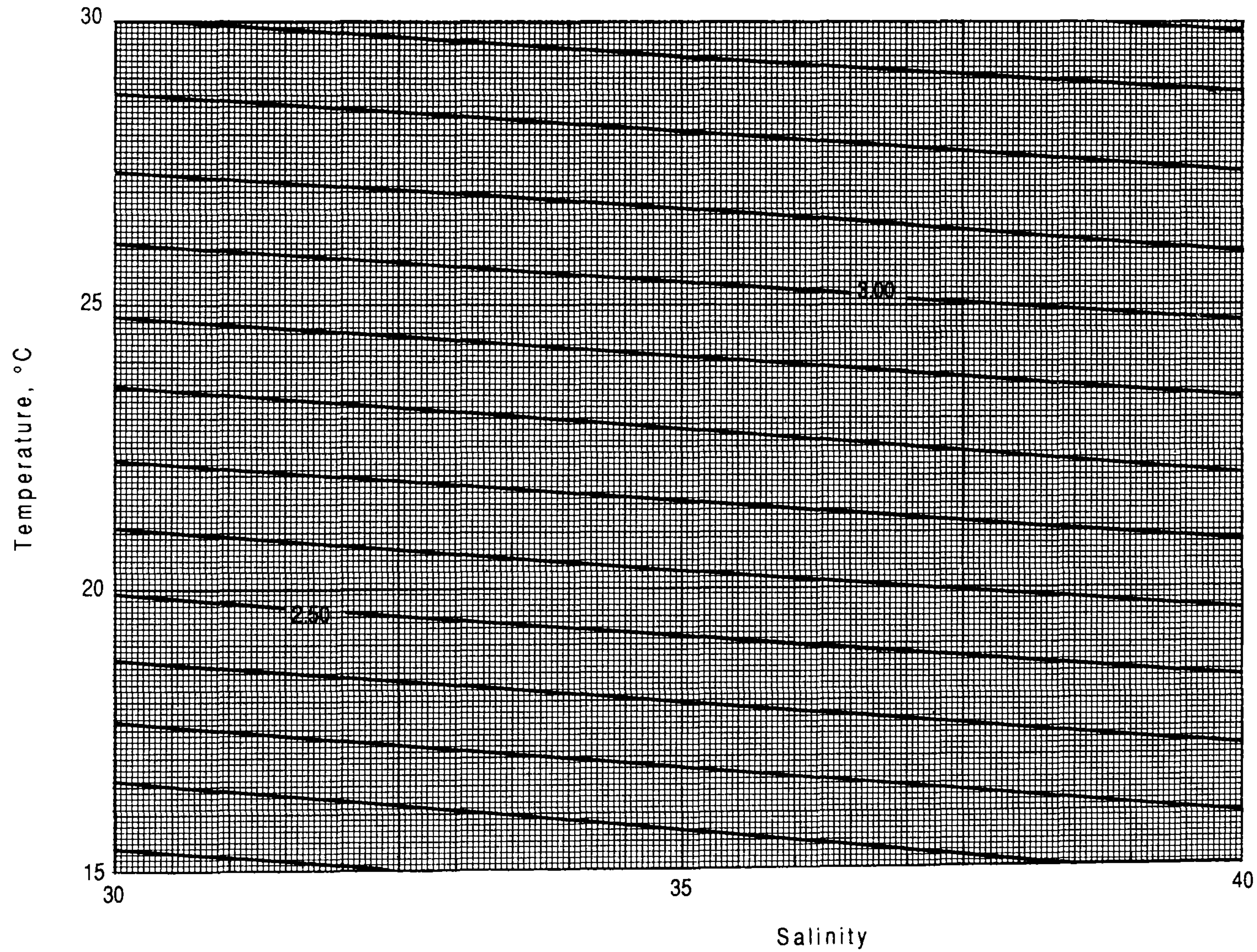
Graph 1b Temperature-pressure correction, $10^8\delta(t, p)$ (m^3/kg) to specific volume (or anomaly of specific volume).



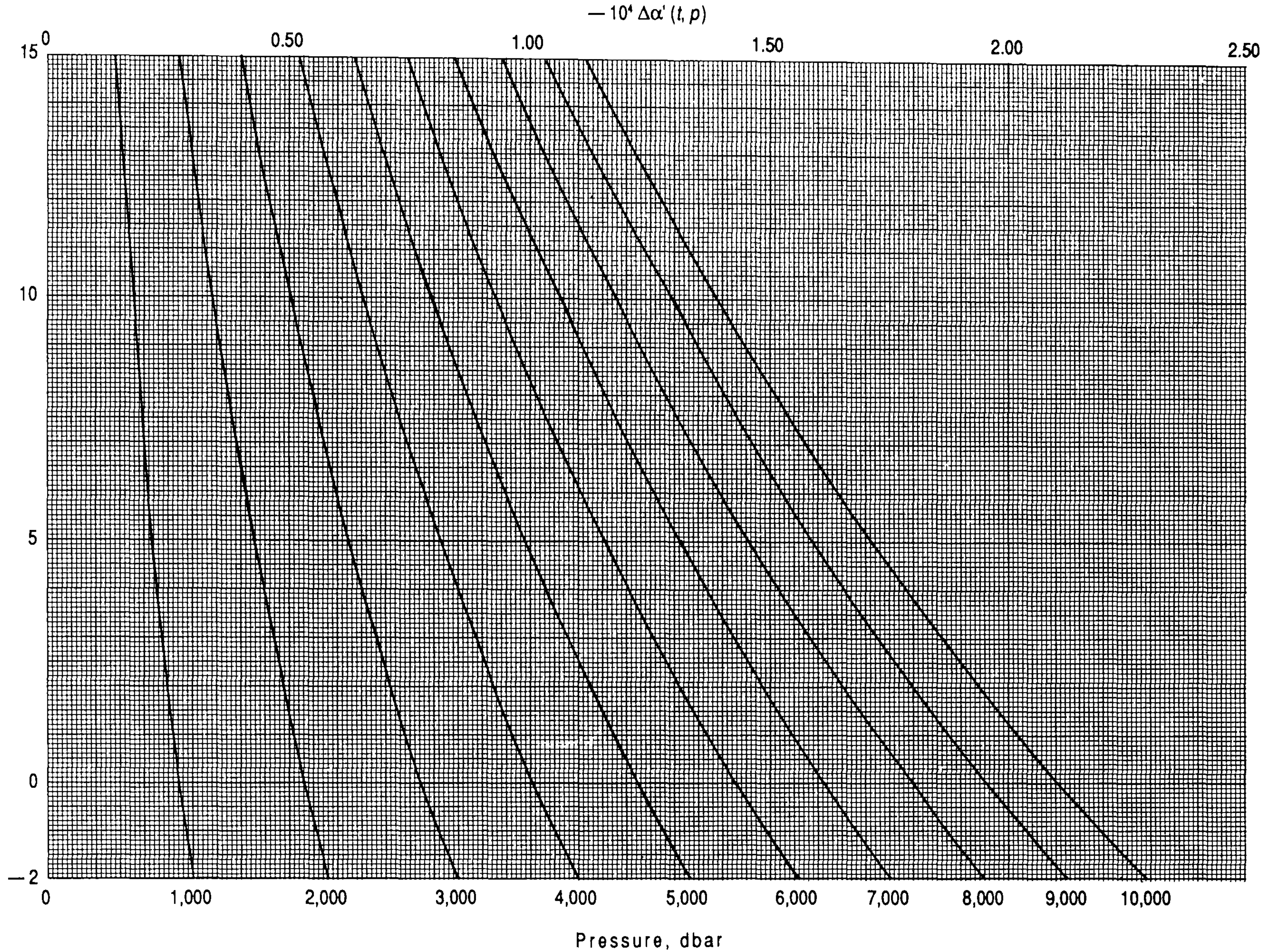
Graph 2 Salinity-pressure correction, $10^8\delta(S, p)$ (m^3/kg) to specific volume (or anomaly of specific volume).



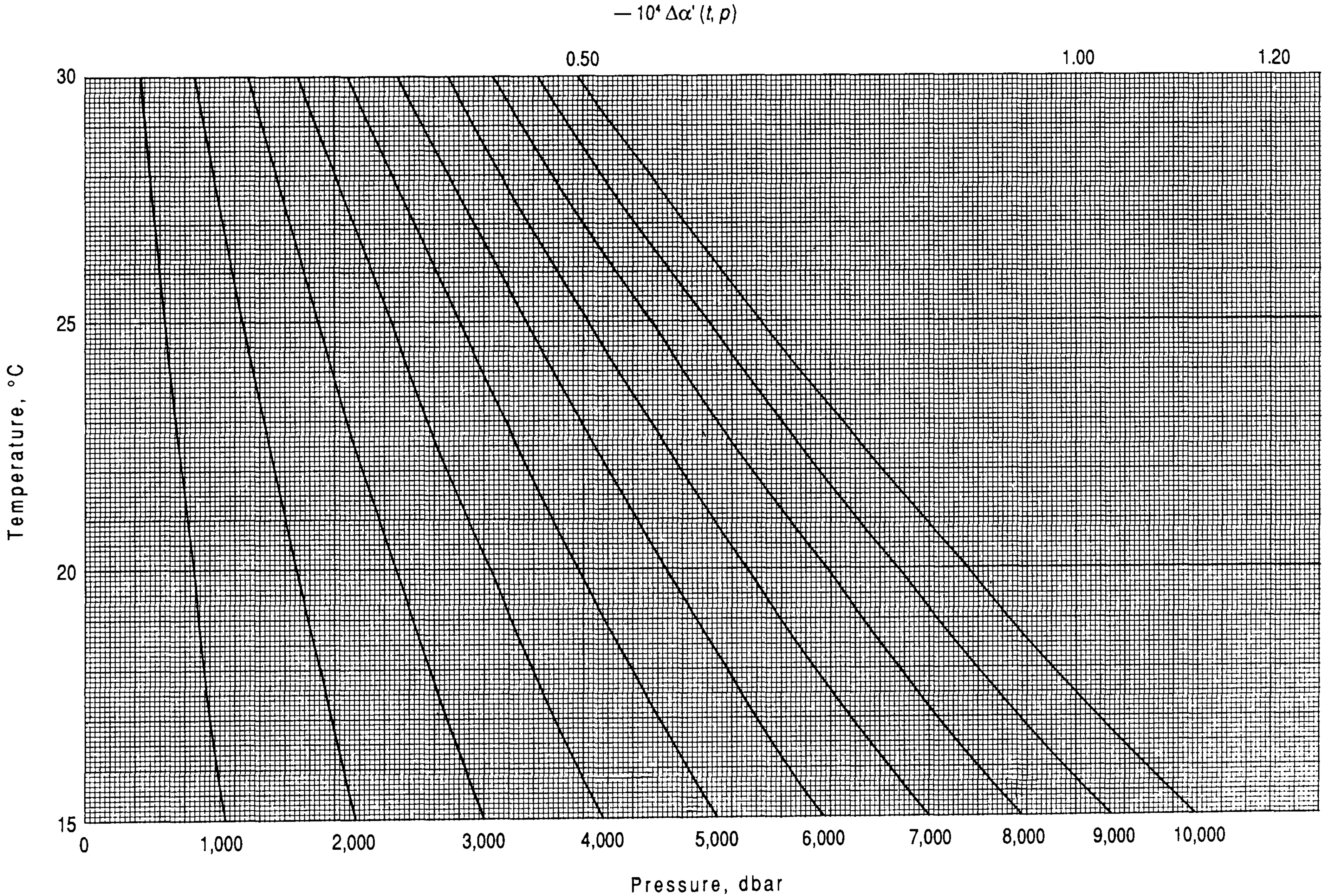
Graph 3a Coefficient of thermal expansion at atmospheric pressure, $10^4\alpha(S, t, 0) = -10^4(1/\rho)\,(\partial\rho/\partial t)$.



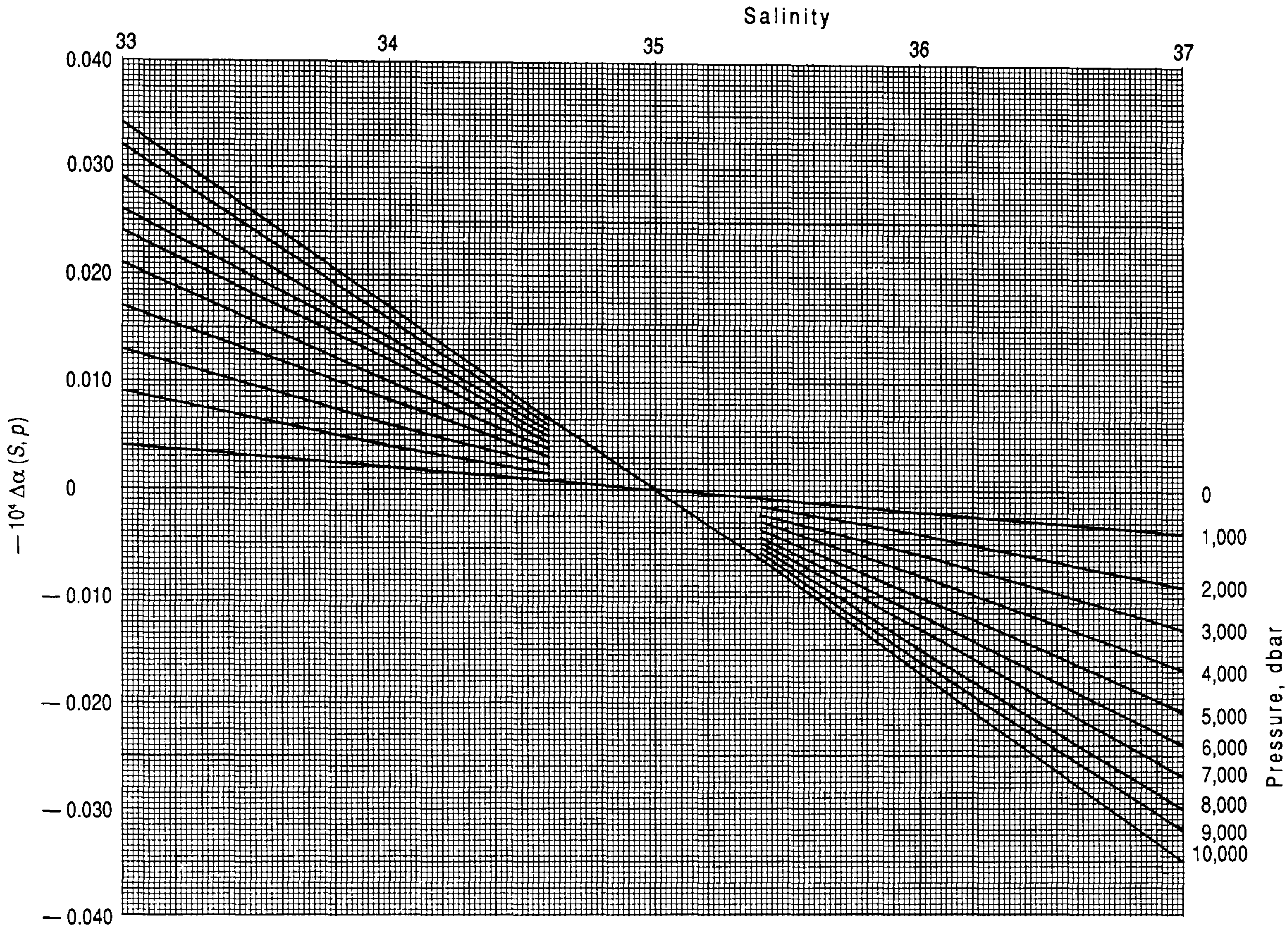
Graph 3b Coefficient of thermal expansion at atmospheric pressure, $10^4\alpha(S, t, 0) = -10^4(1/\rho)\,(\partial\rho/\partial t)$.



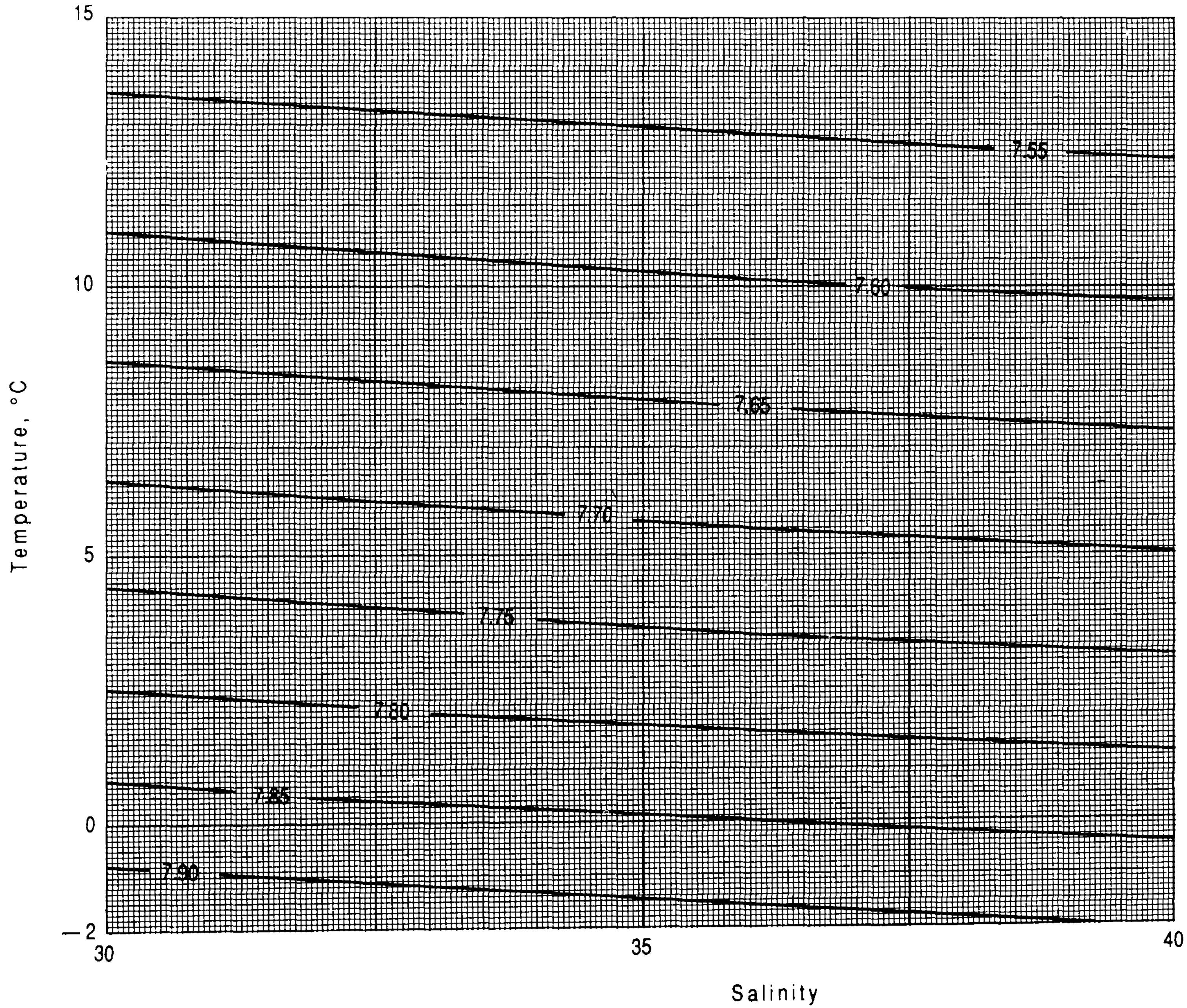
Graph 4a Temperature-pressure correction, $-10^4\ \Delta\alpha'(t, p)$, to coefficient of thermal expansion, $10^4\alpha(S, t, 0)$.



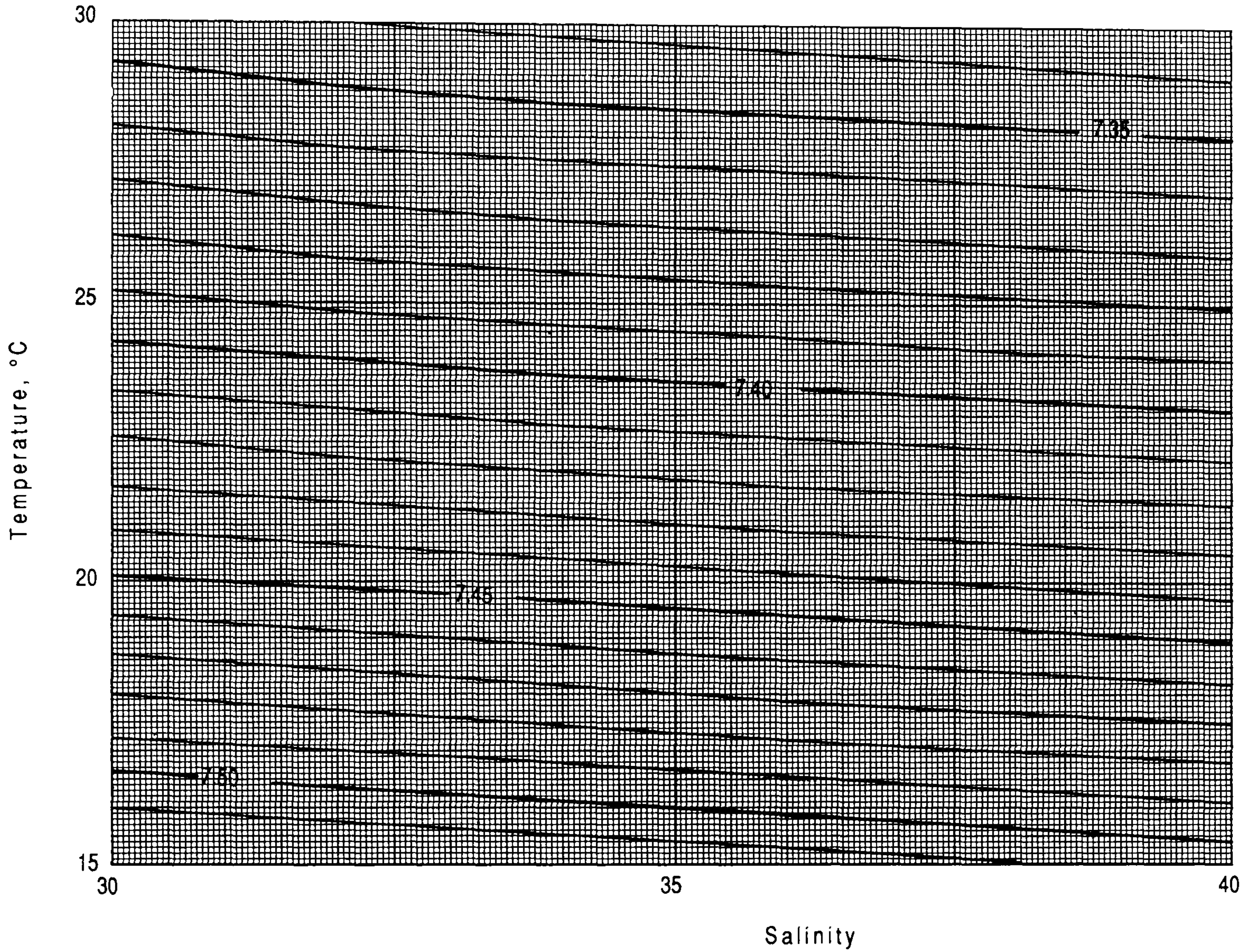
Graph 4b Temperature-pressure correction, $-10^4\ \Delta\alpha'(t, p)$, to coefficient of thermal expansion, $10^4\boldsymbol{\alpha}(S, t, 0)$.



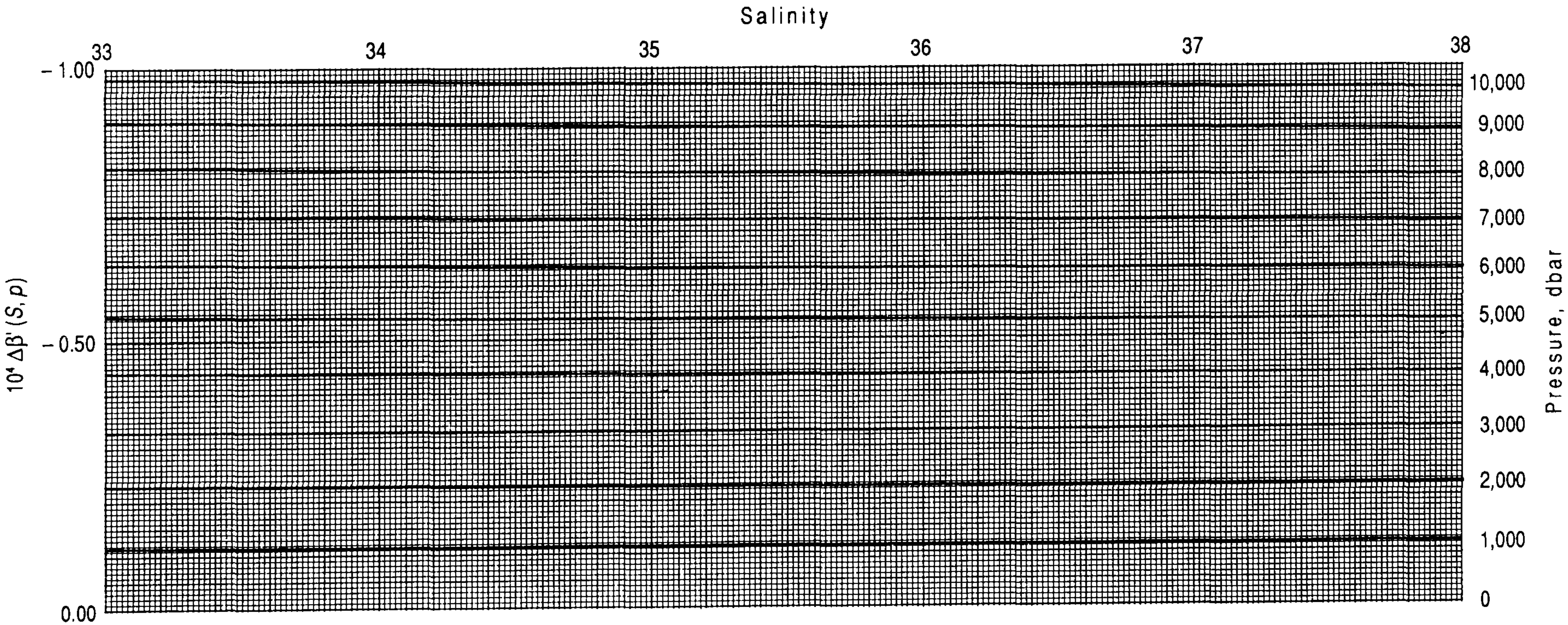
Graph 5 Salinity-pressure correction, $-10^4\,\Delta\alpha(S, p)$, to coefficient of thermal expansion, $10^4\,\alpha(S, t, 0)$.



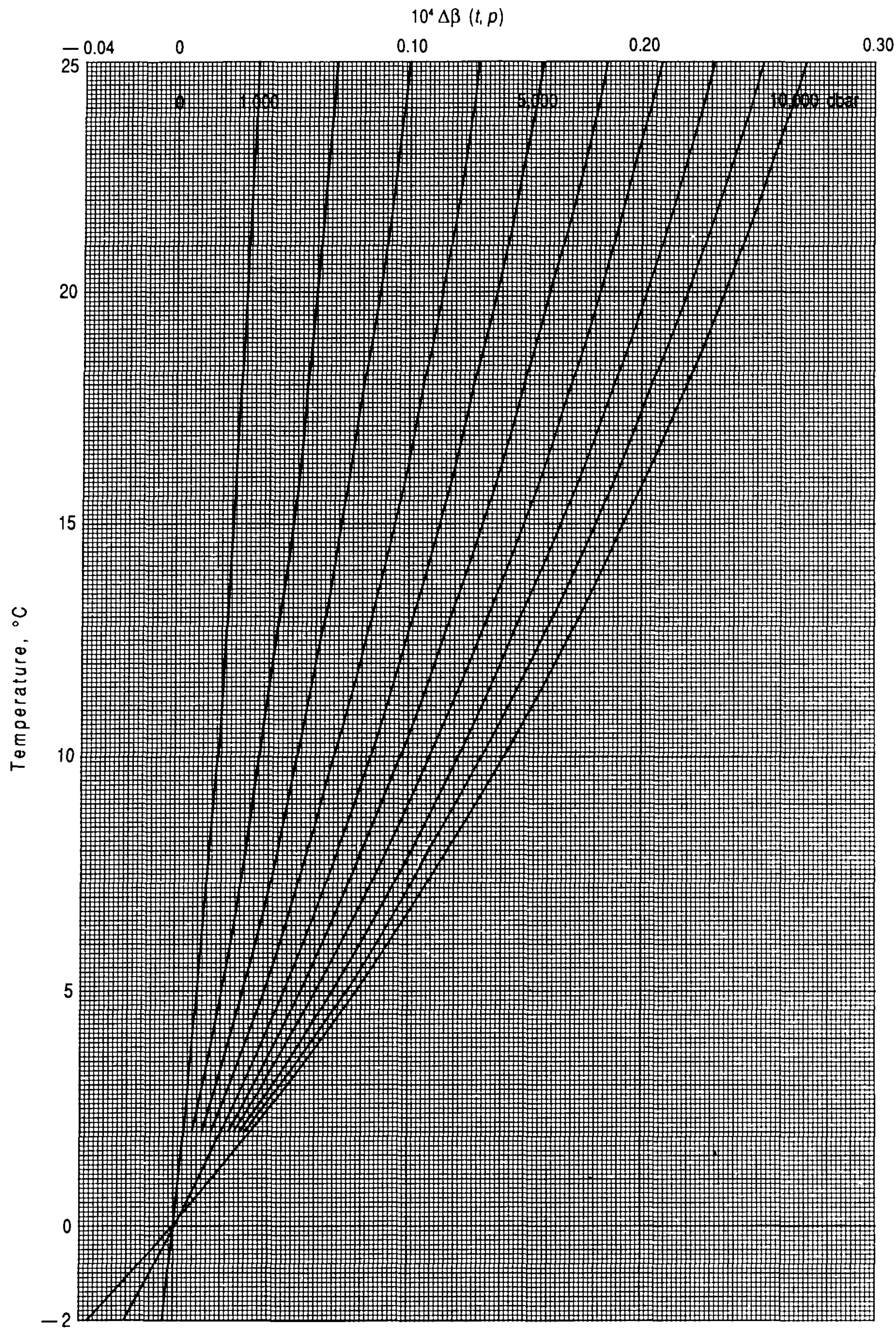
Graph 6a Coefficient of salinity contraction at atmospheric pressure, $10^4\ \beta(S, t, 0) = 10^4(1/\rho)(\partial\rho/\partial S)$.



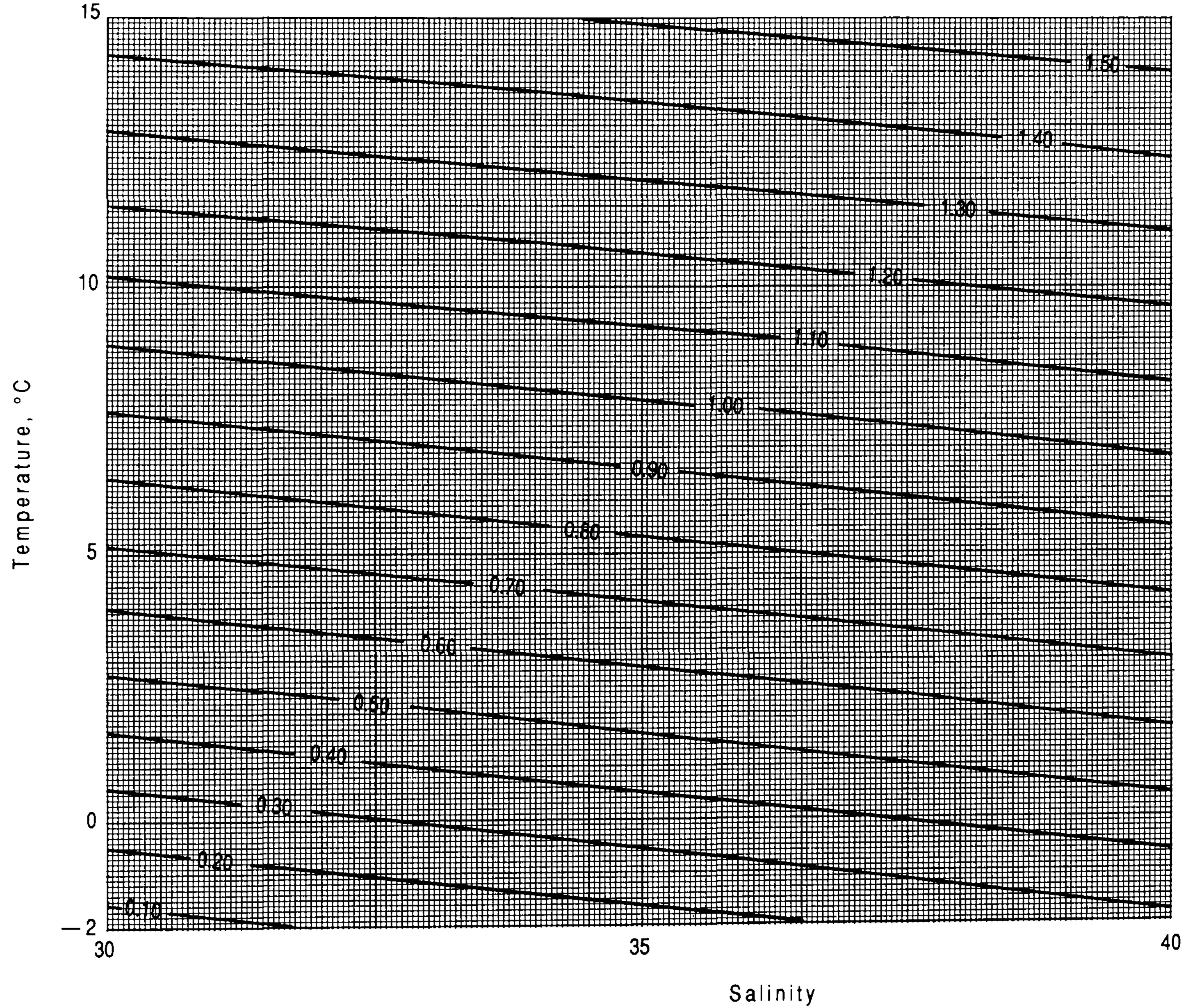
Graph 6b Coefficient of salinity contraction at atmospheric pressure, $10^4\ \beta(S, t, 0) = 10^4(1/\rho)(\partial\rho/\partial S)$.



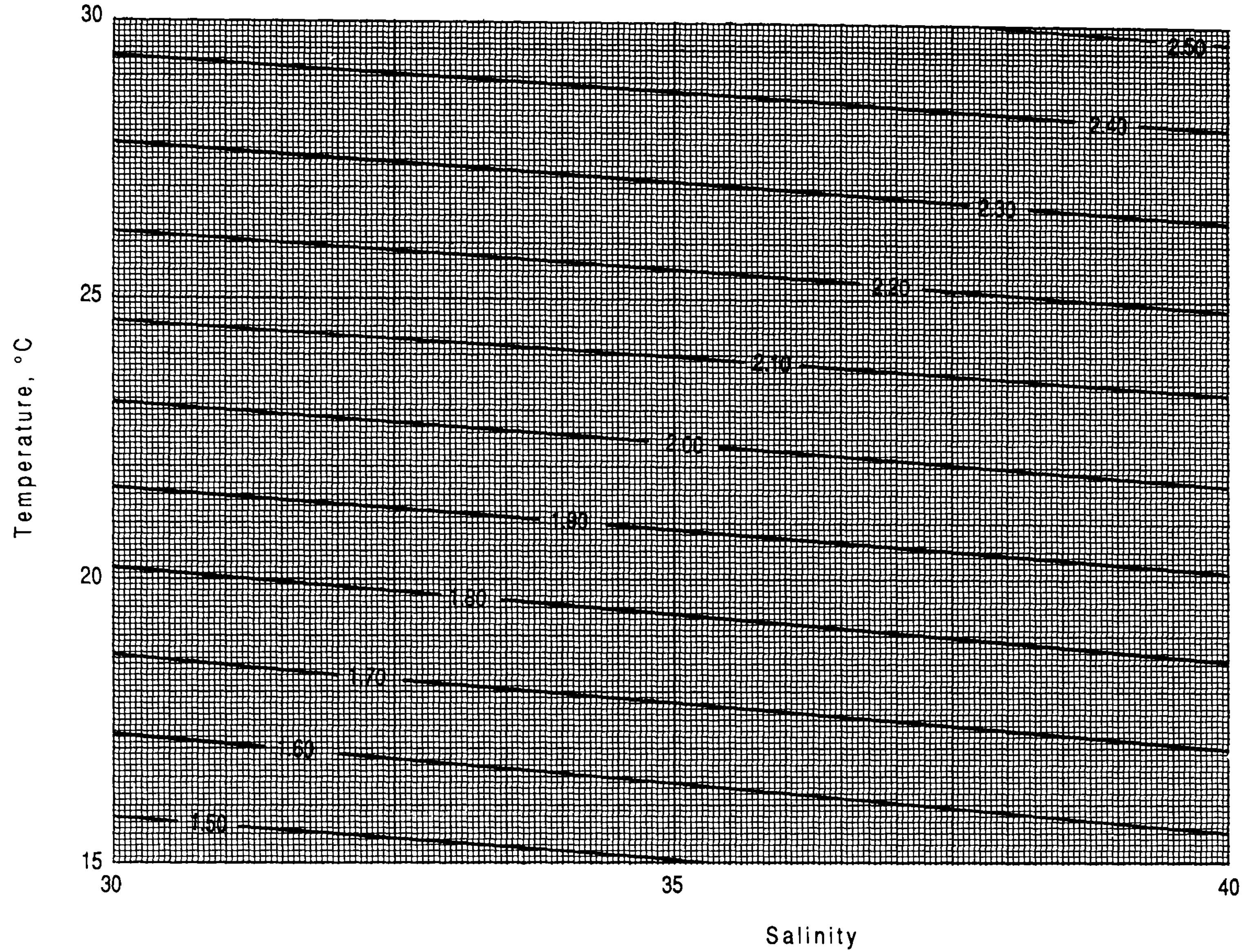
Graph 7 Temperature-pressure correction, $10^4 \Delta\beta(t, p)$, to coefficient of saline contraction, $10^4 \beta(S, t, 0)$.



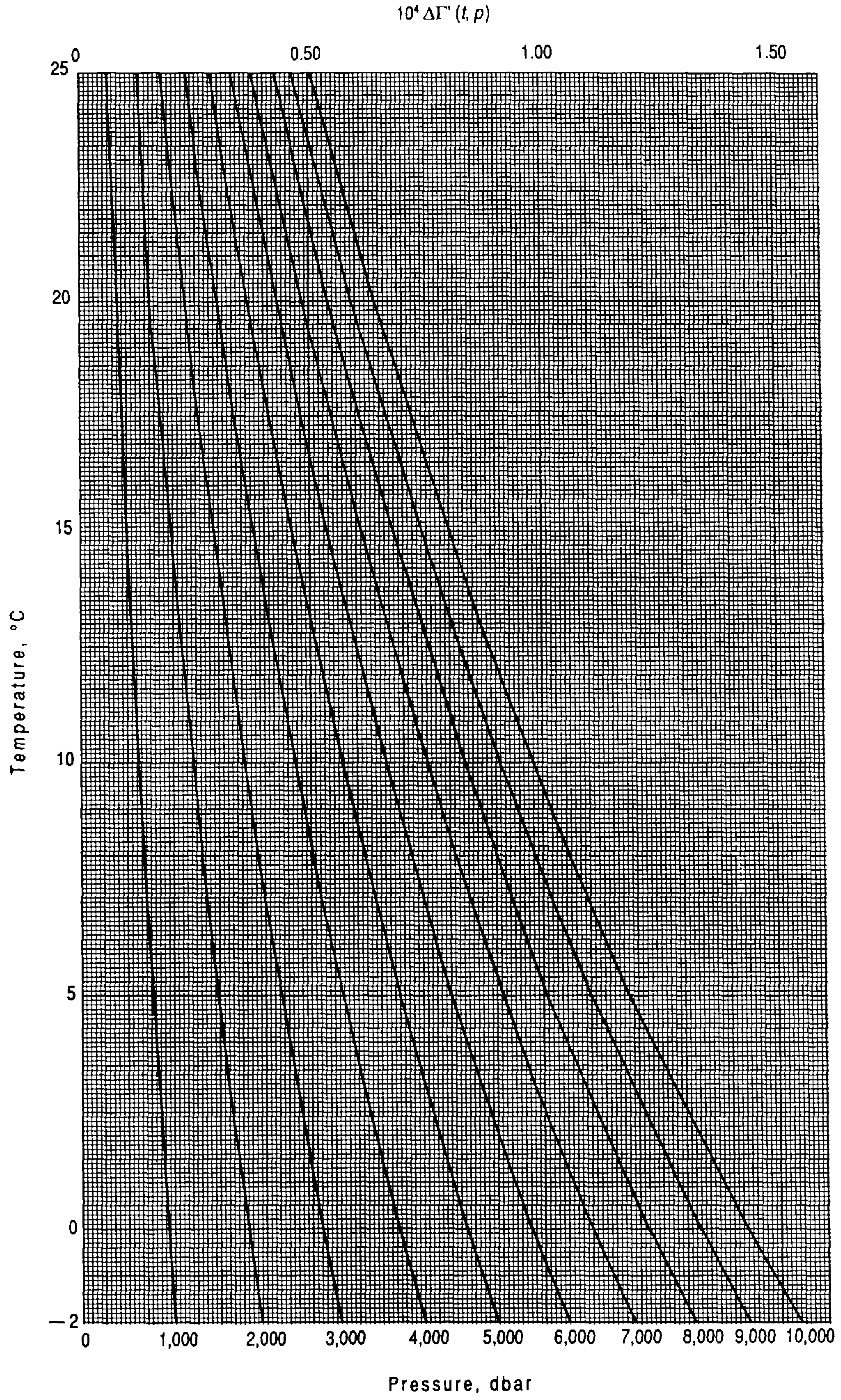
Graph 8 Salinity-pressure correction, $10^4 \Delta \beta'(S, p)$, to coefficient of saline contraction, $10^4 \beta(S, t, 0)$.



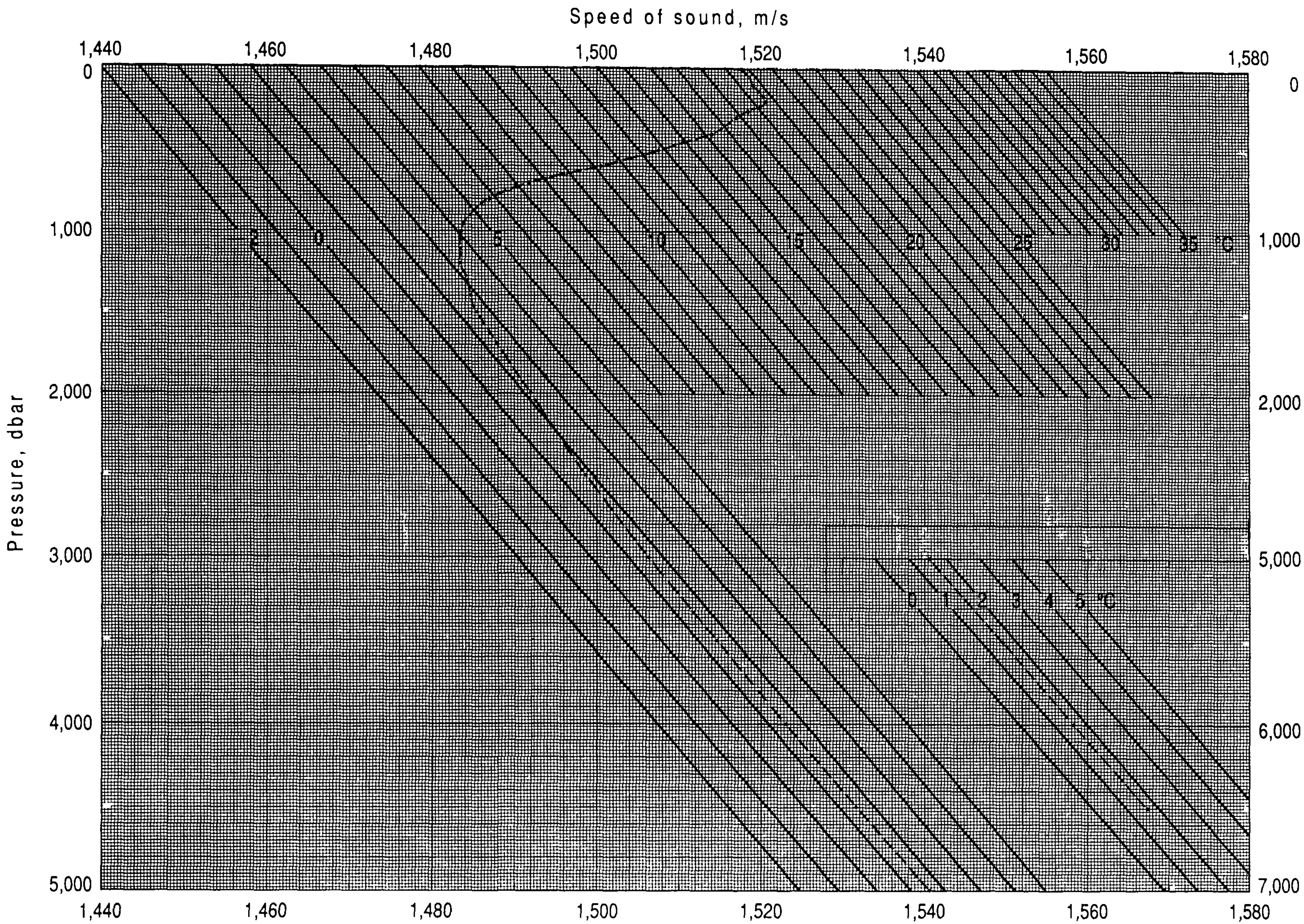
Graph 9a Adiabatic temperature gradient at atmospheric pressure, $10^4\,\Gamma(S, t, 0)$.



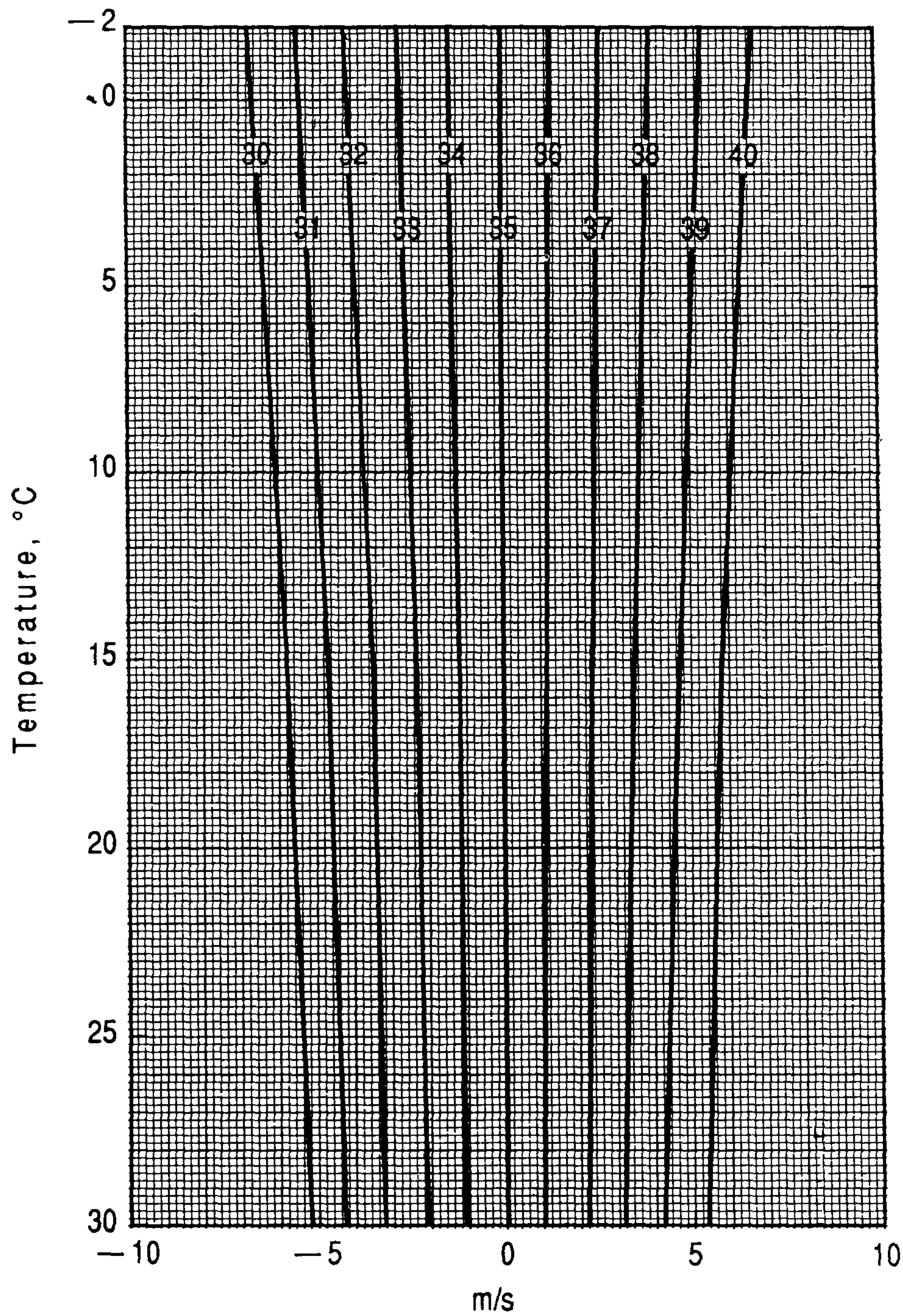
Graph 9b Adiabatic temperature gradient at atmospheric pressure, $10^4\ \Gamma(S, t, 0)$.



Graph 10 Temperature-pressure correction, $10^4\Delta\Gamma'(t, p)$, to adiabatic temperature gradient, $10^4\Gamma(S, t, 0)$



Graph 11 Speed of sound as function of temperature and pressure at constant salinity $S = 35$.



Graph 12 Speed of sound correction for salinity.

Annex 1

Algorithms and Fortran code programs

A1.1 Fortran formulation of dynamic height and potential energy

The dynamic height and potential energy are computed from the surface to the centre of the current pressure interval being evaluated. The calculation assumes a constant value of specific volume anomaly from the first level to the sea surface. The Fortran code should be used only as a guide for implementing these calculations.

Explanation of program variables:

SVA	specific volume anomaly of the current observation
SVAP	previous specific volume anomaly
SVAN(SAL,TMP,PRS,SIGMA)	specific volume anomaly formulation using the 1980 equation of state from Unesco TR 44..
PRS	pressure decibars
PPRS	previous pressure decibars
TMP	temperature degrees celsius
SAL	salinity PPS78.
DELD	dynamic height in dynamic metres from the surface to the centre of the current pressure interval PRS. To initialize the calculation set DELD=0.0.
PE	potential energy from the surface to the centre of the current pressure interval PRS.
AVD	weighting parameter between current and previous pressure interval. AVD=1. for first interval and .5 (i.e. weights half the previous and half current specific volume anomaly in the calculation).

The following Fortran code illustrates the computation of dynamic height anomaly DELD and potential energy anomaly PE. The specific volume anomaly is assumed constant from the first level to the surface.

```
SUBROUTINE DYN(SAL,TMP,PRS,DELD,PE)
CON=1.02E-6
AVD=.5
IF(DELD.EQ.0.0) THEN
AVD=1.0
PPRS=0.0
PE=0.0
PSVA=0.0
END IF
SVA=SVAN(SAL,TMP,PRS,SIGMA)
DELD=DELD+AVD*1.0E-5*(SVA+PSVA)*(PRS-PPRS)
PE=PE+AVD*CON*(PRS*SVA+PPRS*PSVA)*(PRS-PPRS)
PSVA=SVA
PPRS=PRS
END
```

A1.2 Fortran formulation of Brunt-Väisälä frequency and stability parameter

The Brunt-Väisälä frequency and the stability parameter are both calculated using the adiabatic levelling method Fofonoff (1985) and Millard, Owens and Fofonoff (1990). The adiabatic levelling technique estimates the Brunt-Väisälä and stability parameters from the locally adiabatically levelled specific volume anomaly as illustrated in the Fortran code that follows.

```
C BRFRQ ***** BRUNT-VÄISÄLÄ FREQ *****
C  USES 1980 EQUATION OF STATE
     FUNCTION BVFRQ(S,T,P,NOBS,GLAT,PAV,E)
C ************************************
C UNITS:
C     PRESSURE              P        DECIBARS
C     TEMPERATURE           T        DEG CELSIUS (IPTS-68)
C     SALINITY              S        PSU (IPSS-78)
C     GRAVITY               GLAT     M/S^2
C     BOUYANCY FREQ         BVFRQ    CPH
C     STABILITY PAR         E        1/M
C     CENTRE PRES.          PAV      DECIBARS
C R MILLARD FEB 6 1989
C AFTER FORMULATION OF N. P. FOFONOFF & BRECK OWEN'S
      REAL*4 P(1),T(1),S(1)
      GP=GLAT
      IF(GP.LT.9.75) GP=9.80655
      G2=GP*GP*1.E-4
      E=0.0
      BVFRQ=0.0
      IF(NOBS.LT.2) RETURN
      CXX=0.0
      CX=0.0
      CXY=0.0
      CY=0.0
C COMPUTE LEAST SQUARES ESTIMATE OF SPECIFIC VOLUME ANAMOLY
GRADIENT
      DO 20 K=1,NOBS
20    CX =CX+P(K)
      PAV=CX/NOBS
      DO 35 K=1,NOBS
      DATA= SVAN(S(K),THETA(S(K),T(K),P(K),PAV),PAV,SIG)*1.0E-8
      CXY=CXY+DATA*(P(K)-PAV)
      CY =CY+DATA
      CXX=CXX+(P(K)-PAV)**2
35    CONTINUE
      IF(CXX.EQ.0.0) RETURN
      A0=CXY/CXX
      V350P=(1./(SIG+1000.))-DATA
      VBAR=V350P+CY/NOBS
      DVDP=A0
      IF(VBAR).EQ.0.0) RETURN
      E  = -G2*DVDP/(VBAR)**2
      BVFRQ = 572.9578*SIGN(SQRT(ABS(E)),E)
C     DEFINE STABILITY PARAMETER UNITS (1/M)
      E = E/GP
      RETURN
      END
```

A1.3 Fortran formulation of gradient properties

The function GRADY(Y(I),X(I),I,XBAR,YBAR) returns the least squares gradient over the I elements of array Y against X. The average values of X and Y are returned as XBAR and YBAR respectively. The Grady function is used to compute the vertical temperature and salinity gradients. The potential temperature gradient is computed by subtracting the average adiabatic lapse rate from the temperature gradient.

```
      FUNCTION GRADY(Y,P,NOBS,PAV,YBAR)
C  FUNCTION COMPUTE LEAST SQUARES SLOPE 'GRADY' OF Y VERSUS P
C  THE GRADIENT IS REPRESENTIVE OF THE INTERVAL CENTERED AT PAV
      REAL*4 P(1),Y(1)
      GRADY=0.0
      A0=0.0
      CXX=0.0
      CX=0.0
      CXY=0.0
      CY=0.0
      IF(NOBS.LE.1) GO TO 30
      DO 20 K=1,NOBS
20    CX =CX+P(K)
      PAV=CX/NOBS
      DO 35 K=1,NOBS
      CXY=CXY+Y(K)*(P(K)-PAV)
      CY =CY+Y(K)
      CXX=CXX+(P(K)-PAV)**2
35    CONTINUE
      IF(CXX.EQ.0.0) RETURN
      A0=CXY/CXX
      YBAR=CY/NOBS
30    CONTINUE
      GRADY=A0
      RETURN
      END
```

A1.4 Fortran formulation of gravity and Coriolis parameter as a function of latitude

```
C COMPUTE GRAVITY & CORIOLIS PARAMETERS
        FUNCTION GRAVITY(LAT)
C COMPUTE GRAVITY
C GRAVITY VARIATION WITH LATITUDE: ANON (1970) BULLETIN GEODESIQUE
C Fortran formulation after Unesco TR 44 page 27
C **************************************
C UNITS:
C         LATITUDE    LAT        DEGREES
C         GRAVITY                      m/s^2
C **************************************
      REAL LAT
C
      X1 = SIN(LAT/57.29578)
C **************************
      X = X1*X1
      GRAVITY=9.780318*(1.0+(5.2788E-3+2.36E-5*X)*X)
      RETURN
      END


        FUNCTION CORIOL(XLAT)
C     CORIOLIS PARAMETER
C **********************************
C UNITS:
C         LATITUDE    LAT        DEGREES
C         CORIOLIS       CORIOL        s^-1
C *************************************
      PLAT=XLAT/57.29578
      CORIOL=14.5842E-5*SIN(PLAT)
      RETURN
      END
```

Annex 2

Supplement to International Oceanographic Tables Volume 4 (IOT-4) ("Red Sea extension")

Special note: These tables are for seawater of salinity = 40, 41, 42 and 43 only. Users of the tables should however be aware that the latter case, i.e., S = 43 is beyond the range of validity of EOS-80.

Contents of Annex 2

(Note : the table numbers coincide with the corresponding tables in IOT-4)

Table I

Density anomaly, $\gamma(S, t, 0)$ [kg/m^3] at atmospheric pressure

Temp. °C	Salinity 40.0	41.0	42.0	43.0
9.0	31.040	31.825	32.611	33.397
9.1	31.022	31.807	32.593	33.379
9.2	31.005	31.790	32.575	33.361
9.3	30.987	31.772	32.557	33.343
9.4	30.970	31.754	32.539	33.324
9.5	30.952	31.736	32.521	33.306
9.6	30.934	31.718	32.503	33.288
9.7	30.917	31.700	32.485	33.269
9.8	30.899	31.682	32.466	33.251
9.9	30.881	31.664	32.448	33.232
10.0	30.862	31.646	32.429	33.213
10.1	30.844	31.627	32.410	33.194
10.2	30.826	31.609	32.392	33.175
10.3	30.807	31.590	32.373	33.156
10.4	30.789	31.571	32.354	33.137
10.5	30.770	31.552	32.335	33.118
10.6	30.751	31.533	32.316	33.098
10.7	30.733	31.514	32.296	33.079
10.8	30.714	31.495	32.277	33.059
10.9	30.695	31.476	32.258	33.040
11.0	30.675	31.457	32.238	33.020
11.1	30.656	31.437	32.218	33.000
11.2	30.637	31.418	32.199	32.980
11.3	30.618	31.398	32.179	32.960
11.4	30.598	31.378	32.159	32.940
11.5	30.578	31.358	32.139	32.920
11.6	30.559	31.339	32.119	32.899
11.7	30.539	31.319	32.099	32.879
11.8	30.519	31.298	32.078	32.859
11.9	30.499	31.278	32.058	32.838
12.0	30.479	31.258	32.037	32.817
12.1	30.459	31.238	32.017	32.797
12.2	30.438	31.217	31.996	32.776
12.3	30.418	31.197	31.975	32.755
12.4	30.398	31.176	31.955	32.734
12.5	30.377	31.155	31.934	32.713
12.6	30.356	31.134	31.913	32.691
12.7	30.336	31.113	31.891	32.670
12.8	30.315	31.092	31.870	32.649
12.9	30.294	31.071	31.849	32.627
13.0	30.273	31.050	31.828	32.606
13.1	30.252	31.029	31.806	32.584
13.2	30.231	31.007	31.785	32.562
13.3	30.209	30.986	31.763	32.540
13.4	30.188	30.964	31.741	32.518
13.5	30.167	30.943	31.719	32.496
13.6	30.145	30.921	31.697	32.474
13.7	30.123	30.899	31.675	32.452
13.8	30.102	30.877	31.653	32.430
13.9	30.080	30.855	31.631	32.407
14.0	30.058	30.833	31.609	32.385
14.1	30.036	30.811	31.586	32.362
14.2	30.014	30.789	31.564	32.340
14.3	29.991	30.766	31.541	32.317
14.4	29.969	30.744	31.519	32.294

Temp. °C	Salinity 40.0	41.0	42.0	43.0
14.5	29.947	30.721	31.496	32.271
14.6	29.924	30.698	31.473	32.248
14.7	29.902	30.676	31.450	32.225
14.8	29.879	30.653	31.427	32.202
14.9	29.856	30.630	31.404	32.178
15.0	29.834	30.607	31.381	32.155
15.1	29.811	30.584	31.358	32.132
15.2	29.788	30.561	31.334	32.108
15.3	29.765	30.537	31.311	32.085
15.4	29.741	30.514	31.287	32.061
15.5	29.718	30.491	31.264	32.037
15.6	29.695	30.467	31.240	32.013
15.7	29.671	30.444	31.216	31.989
15.8	29.648	30.420	31.192	31.965
15.9	29.624	30.396	31.168	31.941
16.0	29.600	30.372	31.144	31.917
16.1	29.577	30.348	31.120	31.892
16.2	29.553	30.324	31.096	31.868
16.3	29.529	30.300	31.072	31.844
16.4	29.505	30.276	31.047	31.819
16.5	29.481	30.251	31.023	31.794
16.6	29.456	30.227	30.998	31.770
16.7	29.432	30.203	30.974	31.745
16.8	29.408	30.178	30.949	31.720
16.9	29.383	30.153	30.924	31.695
17.0	29.359	30.129	30.899	31.670
17.1	29.334	30.104	30.874	31.645
17.2	29.309	30.079	30.849	31.620
17.3	29.284	30.054	30.824	31.594
17.4	29.260	30.029	30.799	31.569
17.5	29.235	30.004	30.773	31.543
17.6	29.209	29.978	30.748	31.518
17.7	29.184	29.953	30.722	31.492
17.8	29.159	29.928	30.697	31.466
17.9	29.134	29.902	30.671	31.441
18.0	29.108	29.877	30.645	31.415
18.1	29.083	29.851	30.620	31.389
18.2	29.057	29.825	30.594	31.363
18.3	29.032	29.799	30.568	31.337
18.4	29.006	29.774	30.542	31.310
18.5	28.980	29.748	30.516	31.284
18.6	28.954	29.721	30.489	31.258
18.7	28.928	29.695	30.463	31.231
18.8	28.902	29.669	30.437	31.205
18.9	28.876	29.643	30.410	31.178
19.0	28.850	29.616	30.384	31.151
19.1	28.823	29.590	30.357	31.124
19.2	28.797	29.563	30.330	31.098
19.3	28.770	29.537	30.303	31.071
19.4	28.744	29.510	30.276	31.044
19.5	28.717	29.483	30.249	31.016
19.6	28.690	29.456	30.222	30.989
19.7	28.663	29.429	30.195	30.962
19.8	28.637	29.402	30.168	30.935
19.9	28.610	29.375	30.141	30.907

Table I (cont.)

Density anomaly, $\gamma(S, t, 0)$ [kg/m^3] at atmospheric pressure

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	28.583	29.348	30.113	30.880
20.1----	28.555	29.320	30.086	30.852
20.2----	28.528	29.293	30.058	30.824
20.3----	28.501	29.266	30.031	30.797
20.4----	28.473	29.238	30.003	30.769
20.5----	28.446	29.210	29.975	30.741
20.6----	28.418	29.183	29.947	30.713
20.7----	28.391	29.155	29.920	30.685
20.8----	28.363	29.127	29.892	30.657
20.9----	28.335	29.099	29.863	30.628
21.0----	28.307	29.071	29.835	30.600
21.1----	28.279	29.043	29.807	30.572
21.2----	28.251	29.015	29.779	30.543
21.3----	28.223	28.986	29.750	30.515
21.4----	28.195	28.958	29.722	30.486
21.5----	28.167	28.930	29.693	30.457
21.6----	28.138	28.901	29.665	30.428
21.7----	28.110	28.873	29.636	30.400
21.8----	28.081	28.844	29.607	30.371
21.9----	28.053	28.815	29.578	30.342
22.0----	28.024	28.786	29.549	30.312
22.1----	27.995	28.758	29.520	30.283
22.2----	27.966	28.729	29.491	30.254
22.3----	27.938	28.699	29.462	30.225
22.4----	27.909	28.670	29.433	30.195
22.5----	27.880	28.641	29.403	30.166
22.6----	27.850	28.612	29.374	30.136
22.7----	27.821	28.582	29.344	30.107
22.8----	27.792	28.553	29.315	30.077
22.9----	27.762	28.523	29.285	30.047
23.0----	27.733	28.494	29.255	30.017
23.1----	27.703	28.464	29.225	29.987
23.2----	27.674	28.434	29.196	29.957
23.3----	27.644	28.405	29.166	29.927
23.4----	27.614	28.375	29.136	29.897
23.5----	27.584	28.345	29.105	29.867
23.6----	27.555	28.315	29.075	29.836
23.7----	27.525	28.285	29.045	29.806
23.8----	27.494	28.254	29.015	29.775
23.9----	27.464	28.224	28.984	29.745
24.0----	27.434	28.194	28.954	29.714
24.1----	27.404	28.163	28.923	29.683
24.2----	27.373	28.133	28.892	29.653
24.3----	27.343	28.102	28.862	29.622
24.4----	27.312	28.071	28.831	29.591
24.5----	27.282	28.041	28.800	29.560
24.6----	27.251	28.010	28.769	29.529
24.7----	27.220	27.979	28.738	29.498
24.8----	27.189	27.948	28.707	29.466
24.9----	27.158	27.917	28.676	29.435
25.0----	27.127	27.886	28.644	29.404
25.1----	27.096	27.855	28.613	29.372
25.2----	27.065	27.823	28.582	29.341
25.3----	27.034	27.792	28.550	29.309
25.4----	27.003	27.760	28.519	29.277

Temp. °C	Salinity 40.0	41.0	42.0	43.0
25.5----	26.971	27.729	28.487	29.246
25.6----	26.940	27.697	28.455	29.214
25.7----	26.908	27.666	28.424	29.182
25.8----	26.877	27.634	28.392	29.150
25.9----	26.845	27.602	28.360	29.118
26.0----	26.813	27.570	28.328	29.086
26.1----	26.781	27.538	28.296	29.053
26.2----	26.750	27.506	28.263	29.021
26.3----	26.718	27.474	28.231	28.989
26.4----	26.686	27.442	28.199	28.956
26.5----	26.653	27.410	28.167	28.924
26.6----	26.621	27.377	28.134	28.891
26.7----	26.589	27.345	28.102	28.859
26.8----	26.557	27.313	28.069	28.826
26.9----	26.524	27.280	28.036	28.793
27.0----	26.492	27.247	28.004	28.760
27.1----	26.459	27.215	27.971	28.727
27.2----	26.426	27.182	27.938	28.694
27.3----	26.394	27.149	27.905	28.661
27.4----	26.361	27.116	27.872	28.628
27.5----	26.328	27.083	27.839	28.595
27.6----	26.295	27.050	27.806	28.562
27.7----	26.262	27.017	27.772	28.528
27.8----	26.229	26.984	27.739	28.495
27.9----	26.196	26.951	27.706	28.461
28.0----	26.163	26.917	27.672	28.428
28.1----	26.129	26.884	27.639	28.394
28.2----	26.096	26.850	27.605	28.360
28.3----	26.062	26.817	27.571	28.327
28.4----	26.029	26.783	27.538	28.293
28.5----	25.995	26.749	27.504	28.259
28.6----	25.962	26.716	27.470	28.225
28.7----	25.928	26.682	27.436	28.191
28.8----	25.894	26.648	27.402	28.156
28.9----	25.860	26.614	27.368	28.122
29.0----	25.826	26.580	27.334	28.088
29.1----	25.792	26.546	27.299	28.054
29.2----	25.758	26.511	27.265	28.019
29.3----	25.724	26.477	27.231	27.985
29.4----	25.690	26.443	27.196	27.950
29.5----	25.655	26.408	27.162	27.915
29.6----	25.621	26.374	27.127	27.881
29.7----	25.587	26.339	27.092	27.846
29.8----	25.552	26.305	27.058	27.811
29.9----	25.518	26.270	27.023	27.776
30.0----	25.483	26.235	26.988	27.741
30.1----	25.448	26.200	26.953	27.706
30.2----	25.413	26.165	26.918	27.671
30.3----	25.378	26.130	26.883	27.636
30.4----	25.344	26.095	26.848	27.600
30.5----	25.308	26.060	26.812	27.565
30.6----	25.273	26.025	26.777	27.530
30.7----	25.238	25.990	26.742	27.494
30.8----	25.203	25.954	26.706	27.459
30.9----	25.168	25.919	26.671	27.423

Table I (cont.)

Density anomaly, $\gamma(S, t, 0)$ [kg/m^3] at atmospheric pressure

Temp. °C	Salinity 40.0	41.0	42.0	43.0
31.0----	25.132	25.883	26.635	27.387
31.1----	25.097	25.848	26.599	27.351
31.2----	25.061	25.812	26.564	27.316
31.3----	25.026	25.777	26.528	27.280
31.4----	24.990	25.741	26.492	27.244
31.5----	24.954	25.705	26.456	27.208
31.6----	24.919	25.669	26.420	27.172
31.7----	24.883	25.633	26.384	27.135
31.8----	24.847	25.597	26.348	27.099
31.9----	24.811	25.561	26.312	27.063
32.0----	24.775	25.525	26.276	27.027
32.1----	24.739	25.489	26.239	26.990
32.2----	24.703	25.452	26.203	26.954
32.3----	24.666	25.416	26.166	26.917
32.4----	24.630	25.380	26.130	26.880
32.5----	24.594	25.343	26.093	26.844
32.6----	24.557	25.307	26.056	26.807
32.7----	24.521	25.270	26.020	26.770
32.8----	24.484	25.233	25.983	26.733
32.9----	24.447	25.196	25.946	26.696
33.0----	24.411	25.160	25.909	26.659
33.1----	24.374	25.123	25.872	26.622
33.2----	24.337	25.086	25.835	26.585
33.3----	24.300	25.049	25.798	26.548
33.4----	24.263	25.012	25.761	26.510
33.5----	24.226	24.974	25.723	26.473
33.6----	24.189	24.937	25.686	26.435
33.7----	24.152	24.900	25.649	26.398
33.8----	24.114	24.862	25.611	26.360
33.9----	24.077	24.825	25.574	26.323
34.0----	24.040	24.788	25.536	26.285
34.1----	24.002	24.750	25.498	26.247
34.2----	23.965	24.712	25.461	26.209
34.3----	23.927	24.675	25.423	26.171
34.4----	23.889	24.637	25.385	26.134
34.5----	23.852	24.599	25.347	26.096
34.6----	23.814	24.561	25.309	26.057
34.7----	23.776	24.523	25.271	26.019
34.8----	23.738	24.485	25.233	25.981
34.9----	23.700	24.447	25.195	25.943
35.0----	23.662	24.409	25.156	25.904
35.1----	23.624	24.371	25.118	25.866
35.2----	23.586	24.332	25.080	25.827
35.3----	23.547	24.294	25.041	25.789
35.4----	23.509	24.256	25.003	25.750
35.5----	23.471	24.217	24.964	25.712
35.6----	23.432	24.179	24.926	25.673
35.7----	23.394	24.140	24.887	25.634
35.8----	23.355	24.101	24.848	25.595
35.9----	23.316	24.063	24.809	25.556
36.0----	23.278	24.024	24.770	25.517
36.1----	23.239	23.985	24.731	25.478
36.2----	23.200	23.946	24.692	25.439
36.3----	23.161	23.907	24.653	25.400
36.4----	23.122	23.868	24.614	25.361

Table III

Specific volume anomaly, $\delta(S, t, 0)$ $[10^{-8}m^3/kg]$ at atmospheric pressure

S = 40.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
9----	-276.7 1.6 -73.9	-275.1 1.6 -73.9	-273.5 1.6 -73.9	-271.8 1.7 -73.8	-270.2 1.7 -73.8	-268.5 1.7 -73.8	-266.8 1.7 -73.8	-265.1 1.7 -73.8	-263.5 1.7 -73.7	-261.8 1.7 -73.7
10----	-260.0 1.7 -73.7	-258.3 1.7 -73.7	-256.6 1.7 -73.7	-254.9 1.7 -73.7	-253.1 1.8 -73.6	-251.4 1.8 -73.6	-249.6 1.8 -73.6	-247.8 1.8 -73.6	-246.0 1.8 -73.6	-244.3 1.8 -73.6
11----	-242.5 1.8 -73.5	-240.6 1.8 -73.5	-238.8 1.8 -73.5	-237.0 1.8 -73.5	-235.2 1.8 -73.5	-233.3 1.9 -73.5	-231.5 1.9 -73.4	-229.6 1.9 -73.4	-227.7 1.9 -73.4	-225.8 1.9 -73.4
12----	-223.9 1.9 -73.4	-222.0 1.9 -73.4	-220.1 1.9 -73.3	-218.2 1.9 -73.3	-216.3 1.9 -73.3	-214.4 1.9 -73.3	-212.4 2.0 -73.3	-210.5 2.0 -73.3	-208.5 2.0 -73.3	-206.5 2.0 -73.2
13----	-204.5 2.0 -73.2	-202.6 2.0 -73.2	-200.6 2.0 -73.2	-198.6 2.0 -73.2	-196.5 2.0 -73.2	-194.5 2.0 -73.2	-192.5 2.0 -73.1	-190.4 2.0 -73.1	-188.4 2.1 -73.1	-186.3 2.1 -73.1
14----	-184.3 2.1 -73.1	-182.2 2.1 -73.1	-180.1 2.1 -73.1	-178.0 2.1 -73.0	-175.9 2.1 -73.0	-173.8 2.1 -73.0	-171.7 2.1 -73.0	-169.6 2.1 -73.0	-167.4 2.1 -73.0	-165.3 2.2 -73.0
15----	-163.1 2.2 -72.9	-161.0 2.2 -72.9	-158.8 2.2 -72.9	-156.6 2.2 -72.9	-154.4 2.2 -72.9	-152.2 2.2 -72.9	-150.0 2.2 -72.9	-147.8 2.2 -72.8	-145.6 2.2 -72.8	-143.4 2.2 -72.8
16----	-141.2 2.2 -72.8	-138.9 2.3 -72.8	-136.7 2.3 -72.8	-134.4 2.3 -72.8	-132.1 2.3 -72.8	-129.8 2.3 -72.7	-127.6 2.3 -72.7	-125.3 2.3 -72.7	-123.0 2.3 -72.7	-120.7 2.3 -72.7
17----	-118.3 2.3 -72.7	-116.0 2.3 -72.7	-113.7 2.3 -72.7	-111.3 2.4 -72.6	-109.0 2.4 -72.6	-106.6 2.4 -72.6	-104.3 2.4 -72.6	-101.9 2.4 -72.6	-99.5 2.4 -72.6	-97.1 2.4 -72.6
18----	-94.7 2.4 -72.6	-92.3 2.4 -72.5	-89.9 2.4 -72.5	-87.5 2.4 -72.5	-85.0 2.4 -72.5	-82.6 2.4 -72.5	-80.1 2.5 -72.5	-77.7 2.5 -72.5	-75.2 2.5 -72.5	-72.7 2.5 -72.5
19----	-70.3 2.5 -72.4	-67.8 2.5 -72.4	-65.3 2.5 -72.4	-62.8 2.5 -72.4	-60.3 2.5 -72.4	-57.7 2.5 -72.4	-55.2 2.5 -72.4	-52.7 2.5 -72.4	-50.1 2.6 -72.4	-47.6 2.6 -72.4
20----	-45.0 2.6 -72.3	-42.5 2.6 -72.3	-39.9 2.6 -72.3	-37.3 2.6 -72.3	-34.7 2.6 -72.3	-32.1 2.6 -72.3	-29.5 2.6 -72.3	-26.9 2.6 -72.3	-24.3 2.6 -72.3	-21.6 2.6 -72.2
21----	-19.0 2.6 -72.2	-16.4 2.7 -72.2	-13.7 2.7 -72.2	-11.1 2.7 -72.2	-8.4 2.7 -72.2	-5.7 2.7 -72.2	-3.0 2.7 -72.2	-0.3 2.7 -72.2	2.4 2.7 -72.2	5.1 2.7 -72.2

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ [$10^{-8}m^3/kg$] at atmospheric pressure

S = 40.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
22----	7.8 2.7 -72.1	10.5 2.7 -72.1	13.2 2.7 -72.1	16.0 2.7 -72.1	18.7 2.8 -72.1	21.5 2.8 -72.1	24.2 2.8 -72.1	27.0 2.8 -72.1	29.8 2.8 -72.1	32.5 2.8 -72.1
23----	35.3 2.8 -72.1	38.1 2.8 -72.0	40.9 2.8 -72.0	43.7 2.8 -72.0	46.6 2.8 -72.0	49.4 2.8 -72.0	52.2 2.8 -72.0	55.1 2.8 -72.0	57.9 2.9 -72.0	60.8 2.9 -72.0
24----	63.6 2.9 -72.0	66.5 2.9 -72.0	69.4 2.9 -71.9	72.3 2.9 -71.9	75.2 2.9 -71.9	78.1 2.9 -71.9	81.0 2.9 -71.9	83.9 2.9 -71.9	86.8 2.9 -71.9	89.8 2.9 -71.9
25----	92.7 2.9 -71.9	95.6 3.0 -71.9	98.6 3.0 -71.9	101.6 3.0 -71.9	104.5 3.0 -71.9	107.5 3.0 -71.8	110.5 3.0 -71.8	113.5 3.0 -71.8	116.5 3.0 -71.8	119.5 3.0 -71.8
26----	122.5 3.0 -71.8	125.5 3.0 -71.8	128.5 3.0 -71.8	131.6 3.0 -71.8	134.6 3.0 -71.8	137.7 3.1 -71.8	140.7 3.1 -71.8	143.8 3.1 -71.8	146.8 3.1 -71.7	149.9 3.1 -71.7
27----	153.0 3.1 -71.7	156.1 3.1 -71.7	159.2 3.1 -71.7	162.3 3.1 -71.7	165.4 3.1 -71.7	168.5 3.1 -71.7	171.7 3.1 -71.7	174.8 3.1 -71.7	177.9 3.1 -71.7	181.1 3.2 -71.7
28----	184.2 3.2 -71.7	187.4 3.2 -71.7	190.6 3.2 -71.7	193.7 3.2 -71.6	196.9 3.2 -71.6	200.1 3.2 -71.6	203.3 3.2 -71.6	206.5 3.2 -71.6	209.7 3.2 -71.6	213.0 3.2 -71.6
29----	216.2 3.2 -71.6	219.4 3.2 -71.6	222.7 3.2 -71.6	225.9 3.3 -71.6	229.2 3.3 -71.6	232.4 3.3 -71.6	235.7 3.3 -71.6	239.0 3.3 -71.6	242.2 3.3 -71.6	245.5 3.3 -71.5
30----	248.8 3.3 -71.5	252.1 3.3 -71.5	255.4 3.3 -71.5	258.8 3.3 -71.5	262.1 3.3 -71.5	265.4 3.3 -71.5	268.8 3.3 -71.5	272.1 3.4 -71.5	275.4 3.4 -71.5	278.8 3.4 -71.5
31----	282.2 3.4 -71.5	285.5 3.4 -71.5	288.9 3.4 -71.5	292.3 3.4 -71.5	295.7 3.4 -71.5	299.1 3.4 -71.5	302.5 3.4 -71.5	305.9 3.4 -71.4	309.3 3.4 -71.4	312.8 3.4 -71.4
32----	316.2 3.4 -71.4	319.6 3.4 -71.4	323.1 3.5 -71.4	326.5 3.5 -71.4	330.0 3.5 -71.4	333.5 3.5 -71.4	336.9 3.5 -71.4	340.4 3.5 -71.4	343.9 3.5 -71.4	347.4 3.5 -71.4
33----	350.9 3.5 -71.4	354.4 3.5 -71.4	357.9 3.5 -71.4	361.4 3.5 -71.4	365.0 3.5 -71.4	368.5 3.5 -71.4	372.0 3.5 -71.4	375.6 3.6 -71.4	379.1 3.6 -71.3	382.7 3.6 -71.3
34----	386.3 3.6 -71.3	389.8 3.6 -71.3	393.4 3.6 -71.3	397.0 3.6 -71.3	400.6 3.6 -71.3	404.2 3.6 -71.3	407.8 3.6 -71.3	411.4 3.6 -71.3	415.0 3.6 -71.3	418.7 3.6 -71.3
35----	422.3 3.6 -71.3	425.9 3.6 -71.3	429.6 3.7 -71.3	433.2 3.7 -71.3	436.9 3.7 -71.3	440.6 3.7 -71.3	444.2 3.7 -71.3	447.9 3.7 -71.3	451.6 3.7 -71.3	455.3 3.7 -71.3

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ $[10^{-8}m^3/kg]$ at atmospheric pressure

S = 41.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
9----	-350.5 1.6 -73.8	-348.9 1.7 -73.8	-347.2 1.7 -73.8	-345.6 1.7 -73.8	-343.9 1.7 -73.7	-342.2 1.7 -73.7	-340.5 1.7 -73.7	-338.8 1.7 -73.7	-337.1 1.7 -73.7	-335.4 1.7 -73.7
10----	-333.7 1.7 -73.6	-332.0 1.7 -73.6	-330.2 1.8 -73.6	-328.5 1.8 -73.6	-326.7 1.8 -73.6	-324.9 1.8 -73.6	-323.1 1.8 -73.5	-321.3 1.8 -73.5	-319.5 1.8 -73.5	-317.7 1.8 -73.5
11----	-315.9 1.8 -73.5	-314.1 1.8 -73.5	-312.3 1.8 -73.4	-310.4 1.9 -73.4	-308.6 1.9 -73.4	-306.7 1.9 -73.4	-304.8 1.9 -73.4	-303.0 1.9 -73.4	-301.1 1.9 -73.3	-299.2 1.9 -73.3
12----	-297.3 1.9 -73.3	-295.3 1.9 -73.3	-293.4 1.9 -73.3	-291.5 1.9 -73.3	-289.5 2.0 -73.2	-287.6 2.0 -73.2	-285.6 2.0 -73.2	-283.7 2.0 -73.2	-281.7 2.0 -73.2	-279.7 2.0 -73.2
13----	-277.7 2.0 -73.2	-275.7 2.0 -73.1	-273.7 2.0 -73.1	-271.7 2.0 -73.1	-269.6 2.0 -73.1	-267.6 2.0 -73.1	-265.6 2.1 -73.1	-263.5 2.1 -73.1	-261.4 2.1 -73.0	-259.4 2.1 -73.0
14----	-257.3 2.1 -73.0	-255.2 2.1 -73.0	-253.1 2.1 -73.0	-251.0 2.1 -73.0	-248.9 2.1 -73.0	-246.7 2.1 -72.9	-244.6 2.1 -72.9	-242.5 2.1 -72.9	-240.3 2.2 -72.9	-238.2 2.2 -72.9
15----	-236.0 2.2 -72.9	-233.8 2.2 -72.9	-231.6 2.2 -72.8	-229.5 2.2 -72.8	-227.3 2.2 -72.8	-225.1 2.2 -72.8	-222.8 2.2 -72.8	-220.6 2.2 -72.8	-218.4 2.2 -72.8	-216.1 2.2 -72.8
16----	-213.9 2.3 -72.7	-211.6 2.3 -72.7	-209.4 2.3 -72.7	-207.1 2.3 -72.7	-204.8 2.3 -72.7	-202.5 2.3 -72.7	-200.2 2.3 -72.7	-197.9 2.3 -72.7	-195.6 2.3 -72.6	-193.3 2.3 -72.6
17----	-191.0 2.3 -72.6	-188.6 2.3 -72.6	-186.3 2.4 -72.6	-183.9 2.4 -72.6	-181.5 2.4 -72.6	-179.2 2.4 -72.6	-176.8 2.4 -72.5	-174.4 2.4 -72.5	-172.0 2.4 -72.5	-169.6 2.4 -72.5
18----	-167.2 2.4 -72.5	-164.8 2.4 -72.5	-162.4 2.4 -72.5	-159.9 2.4 -72.5	-157.5 2.5 -72.4	-155.0 2.5 -72.4	-152.6 2.5 -72.4	-150.1 2.5 -72.4	-147.6 2.5 -72.4	-145.1 2.5 -72.4
19----	-142.6 2.5 -72.4	-140.1 2.5 -72.4	-137.6 2.5 -72.4	-135.1 2.5 -72.3	-132.6 2.5 -72.3	-130.1 2.5 -72.3	-127.5 2.5 -72.3	-125.0 2.6 -72.3	-122.4 2.6 -72.3	-119.9 2.6 -72.3
20----	-117.3 2.6 -72.3	-114.7 2.6 -72.3	-112.1 2.6 -72.3	-109.6 2.6 -72.2	-107.0 2.6 -72.2	-104.3 2.6 -72.2	-101.7 2.6 -72.2	-99.1 2.6 -72.2	-96.5 2.6 -72.2	-93.8 2.6 -72.2
21----	-91.2 2.7 -72.2	-88.5 2.7 -72.2	-85.9 2.7 -72.2	-83.2 2.7 -72.1	-80.5 2.7 -72.1	-77.8 2.7 -72.1	-75.1 2.7 -72.1	-72.4 2.7 -72.1	-69.7 2.7 -72.1	-67.0 2.7 -72.1

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ $[10^{-8}m^3/kg]$ at atmospheric pressure

S = 41.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
22----	-64.3 2.7 -72.1	-61.6 2.7 -72.1	-58.8 2.7 -72.1	-56.1 2.8 -72.1	-53.3 2.8 -72.0	-50.6 2.8 -72.0	-47.8 2.8 -72.0	-45.0 2.8 -72.0	-42.2 2.8 -72.0	-39.5 2.8 -72.0
23----	-36.7 2.8 -72.0	-33.8 2.8 -72.0	-31.0 2.8 -72.0	-28.2 2.8 -72.0	-25.4 2.8 -72.0	-22.5 2.8 -71.9	-19.7 2.9 -71.9	-16.9 2.9 -71.9	-14.0 2.9 -71.9	-11.1 2.9 -71.9
24----	-8.3 2.9 -71.9	-5.4 2.9 -71.9	-2.5 2.9 -71.9	0.4 2.9 -71.9	3.3 2.9 -71.9	6.2 2.9 -71.9	9.1 2.9 -71.9	12.1 2.9 -71.8	15.0 2.9 -71.8	17.9 2.9 -71.8
25----	20.9 3.0 -71.8	23.8 3.0 -71.8	26.8 3.0 -71.8	29.8 3.0 -71.8	32.7 3.0 -71.8	35.7 3.0 -71.8	38.7 3.0 -71.8	41.7 3.0 -71.8	44.7 3.0 -71.8	47.7 3.0 -71.8
26----	50.7 3.0 -71.7	53.8 3.0 -71.7	56.8 3.0 -71.7	59.8 3.0 -71.7	62.9 3.1 -71.7	65.9 3.1 -71.7	69.0 3.1 -71.7	72.1 3.1 -71.7	75.2 3.1 -71.7	78.2 3.1 -71.7
27----	81.3 3.1 -71.7	84.4 3.1 -71.7	87.5 3.1 -71.7	90.6 3.1 -71.7	93.8 3.1 -71.6	96.9 3.1 -71.6	100.0 3.1 -71.6	103.2 3.1 -71.6	106.3 3.2 -71.6	109.5 3.2 -71.6
28----	112.6 3.2 -71.6	115.8 3.2 -71.6	119.0 3.2 -71.6	122.2 3.2 -71.6	125.4 3.2 -71.6	128.5 3.2 -71.6	131.8 3.2 -71.6	135.0 3.2 -71.6	138.2 3.2 -71.6	141.4 3.2 -71.5
29----	144.6 3.2 -71.5	147.9 3.2 -71.5	151.1 3.3 -71.5	154.4 3.3 -71.5	157.6 3.3 -71.5	160.9 3.3 -71.5	164.2 3.3 -71.5	167.5 3.3 -71.5	170.8 3.3 -71.5	174.0 3.3 -71.5
30----	177.4 3.3 -71.5	180.7 3.3 -71.5	184.0 3.3 -71.5	187.3 3.3 -71.5	190.6 3.3 -71.5	194.0 3.3 -71.5	197.3 3.4 -71.4	200.7 3.4 -71.4	204.0 3.4 -71.4	207.4 3.4 -71.4
31----	210.7 3.4 -71.4	214.1 3.4 -71.4	217.5 3.4 -71.4	220.9 3.4 -71.4	224.3 3.4 -71.4	227.7 3.4 -71.4	231.1 3.4 -71.4	234.5 3.4 -71.4	238.0 3.4 -71.4	241.4 3.4 -71.4
32----	244.8 3.4 -71.4	248.3 3.5 -71.4	251.7 3.5 -71.4	255.2 3.5 -71.4	258.6 3.5 -71.4	262.1 3.5 -71.3	265.6 3.5 -71.3	269.1 3.5 -71.3	272.6 3.5 -71.3	276.1 3.5 -71.3
33----	279.6 3.5 -71.3	283.1 3.5 -71.3	286.6 3.5 -71.3	290.1 3.5 -71.3	293.7 3.5 -71.3	297.2 3.5 -71.3	300.8 3.6 -71.3	304.3 3.6 -71.3	307.9 3.6 -71.3	311.4 3.6 -71.3
34----	315.0 3.6 -71.3	318.6 3.6 -71.3	322.2 3.6 -71.3	325.7 3.6 -71.3	329.3 3.6 -71.3	332.9 3.6 -71.3	336.6 3.6 -71.3	340.2 3.6 -71.2	343.8 3.6 -71.2	347.4 3.6 -71.2
35----	351.1 3.6 -71.2	354.7 3.6 -71.2	358.4 3.7 -71.2	362.0 3.7 -71.2	365.7 3.7 -71.2	369.3 3.7 -71.2	373.0 3.7 -71.2	376.7 3.7 -71.2	380.4 3.7 -71.2	384.1 3.7 -71.2

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ [$10^{-8}m^3/kg$] at atmospheric pressure

S = 42.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
9----	-424.3 1.7 -73.7	-422.6 1.7 -73.7	-420.9 1.7 -73.7	-419.3 1.7 -73.7	-417.6 1.7 -73.7	-415.9 1.7 -73.7	-414.2 1.7 -73.6	-412.5 1.7 -73.6	-410.7 1.7 -73.6	-409.0 1.7 -73.6
10----	-407.3 1.8 -73.6	-405.5 1.8 -73.5	-403.7 1.8 -73.5	-402.0 1.8 -73.5	-400.2 1.8 -73.5	-398.4 1.8 -73.5	-396.6 1.8 -73.5	-394.8 1.8 -73.4	-393.0 1.8 -73.4	-391.2 1.8 -73.4
11----	-389.3 1.8 -73.4	-387.5 1.9 -73.4	-385.6 1.9 -73.4	-383.8 1.9 -73.3	-381.9 1.9 -73.3	-380.0 1.9 -73.3	-378.1 1.9 -73.3	-376.2 1.9 -73.3	-374.3 1.9 -73.3	-372.4 1.9 -73.3
12----	-370.5 1.9 -73.2	-368.6 1.9 -73.2	-366.6 1.9 -73.2	-364.7 2.0 -73.2	-362.7 2.0 -73.2	-360.7 2.0 -73.2	-358.8 2.0 -73.1	-356.8 2.0 -73.1	-354.8 2.0 -73.1	-352.8 2.0 -73.1
13----	-350.8 2.0 -73.1	-348.8 2.0 -73.1	-346.7 2.0 -73.1	-344.7 2.0 -73.0	-342.7 2.1 -73.0	-340.6 2.1 -73.0	-338.5 2.1 -73.0	-336.5 2.1 -73.0	-334.4 2.1 -73.0	-332.3 2.1 -73.0
14----	-330.2 2.1 -72.9	-328.1 2.1 -72.9	-326.0 2.1 -72.9	-323.9 2.1 -72.9	-321.8 2.1 -72.9	-319.6 2.1 -72.9	-317.5 2.2 -72.9	-315.3 2.2 -72.8	-313.2 2.2 -72.8	-311.0 2.2 -72.8
15----	-308.8 2.2 -72.8	-306.6 2.2 -72.8	-304.4 2.2 -72.8	-302.2 2.2 -72.8	-300.0 2.2 -72.7	-297.8 2.2 -72.7	-295.6 2.2 -72.7	-293.3 2.2 -72.7	-291.1 2.3 -72.7	-288.8 2.3 -72.7
16----	-286.6 2.3 -72.7	-284.3 2.3 -72.7	-282.0 2.3 -72.6	-279.7 2.3 -72.6	-277.4 2.3 -72.6	-275.1 2.3 -72.6	-272.8 2.3 -72.6	-270.5 2.3 -72.6	-268.2 2.3 -72.6	-265.8 2.3 -72.6
17----	-263.5 2.4 -72.5	-261.1 2.4 -72.5	-258.8 2.4 -72.5	-256.4 2.4 -72.5	-254.0 2.4 -72.5	-251.7 2.4 -72.5	-249.3 2.4 -72.5	-246.9 2.4 -72.5	-244.5 2.4 -72.5	-242.1 2.4 -72.4
18----	-239.6 2.4 -72.4	-237.2 2.4 -72.4	-234.8 2.4 -72.4	-232.3 2.5 -72.4	-229.9 2.5 -72.4	-227.4 2.5 -72.4	-224.9 2.5 -72.4	-222.4 2.5 -72.4	-220.0 2.5 -72.3	-217.5 2.5 -72.3
19----	-215.0 2.5 -72.3	-212.5 2.5 -72.3	-209.9 2.5 -72.3	-207.4 2.5 -72.3	-204.9 2.5 -72.3	-202.3 2.5 -72.3	-199.8 2.6 -72.3	-197.2 2.6 -72.2	-194.7 2.6 -72.2	-192.1 2.6 -72.2
20----	-189.5 2.6 -72.2	-186.9 2.6 -72.2	-184.3 2.6 -72.2	-181.7 2.6 -72.2	-179.1 2.6 -72.2	-176.5 2.6 -72.2	-173.9 2.6 -72.2	-171.2 2.6 -72.1	-168.6 2.6 -72.1	-166.0 2.7 -72.1
21----	-163.3 2.7 -72.1	-160.6 2.7 -72.1	-158.0 2.7 -72.1	-155.3 2.7 -72.1	-152.6 2.7 -72.1	-149.9 2.7 -72.1	-147.2 2.7 -72.1	-144.5 2.7 -72.0	-141.8 2.7 -72.0	-139.0 2.7 -72.0

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ [$10^{-8}m^3/kg$] at atmospheric pressure

S = 42.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
22----	-136.3 2.7 -72.0	-133.6 2.7 -72.0	-130.8 2.8 -72.0	-128.1 2.8 -72.0	-125.3 2.8 -72.0	-122.5 2.8 -72.0	-119.8 2.8 -72.0	-117.0 2.8 -72.0	-114.2 2.8 -71.9	-111.4 2.8 -71.9
23----	-108.6 2.8 -71.9	-105.8 2.8 -71.9	-102.9 2.8 -71.9	-100.1 2.8 -71.9	-97.3 2.8 -71.9	-94.4 2.9 -71.9	-91.6 2.9 -71.9	-88.7 2.9 -71.9	-85.9 2.9 -71.9	-83.0 2.9 -71.8
24----	-80.1 2.9 -71.8	-77.2 2.9 -71.8	-74.3 2.9 -71.8	-71.4 2.9 -71.8	-68.5 2.9 -71.8	-65.6 2.9 -71.8	-62.7 2.9 -71.8	-59.7 2.9 -71.8	-56.8 2.9 -71.8	-53.8 3.0 -71.8
25----	-50.9 3.0 -71.8	-47.9 3.0 -71.8	-45.0 3.0 -71.7	-42.0 3.0 -71.7	-39.0 3.0 -71.7	-36.0 3.0 -71.7	-33.0 3.0 -71.7	-30.0 3.0 -71.7	-27.0 3.0 -71.7	-24.0 3.0 -71.7
26----	-20.9 3.0 -71.7	-17.9 3.0 -71.7	-14.9 3.0 -71.7	-11.8 3.1 -71.7	-8.8 3.1 -71.7	-5.7 3.1 -71.6	-2.6 3.1 -71.6	0.4 3.1 -71.6	3.5 3.1 -71.6	6.6 3.1 -71.6
27----	9.7 3.1 -71.6	12.8 3.1 -71.6	15.9 3.1 -71.6	19.1 3.1 -71.6	22.2 3.1 -71.6	25.3 3.1 -71.6	28.5 3.1 -71.6	31.6 3.2 -71.6	34.8 3.2 -71.6	37.9 3.2 -71.6
28----	41.1 3.2 -71.5	44.3 3.2 -71.5	47.4 3.2 -71.5	50.6 3.2 -71.5	53.8 3.2 -71.5	57.0 3.2 -71.5	60.2 3.2 -71.5	63.5 3.2 -71.5	66.7 3.2 -71.5	69.9 3.2 -71.5
29----	73.2 3.2 -71.5	76.4 3.3 -71.5	79.7 3.3 -71.5	82.9 3.3 -71.5	86.2 3.3 -71.5	89.5 3.3 -71.5	92.7 3.3 -71.4	96.0 3.3 -71.4	99.3 3.3 -71.4	102.6 3.3 -71.4
30----	105.9 3.3 -71.4	109.2 3.3 -71.4	112.6 3.3 -71.4	115.9 3.3 -71.4	119.2 3.3 -71.4	122.6 3.3 -71.4	125.9 3.4 -71.4	129.3 3.4 -71.4	132.6 3.4 -71.4	136.0 3.4 -71.4
31----	139.4 3.4 -71.4	142.8 3.4 -71.4	146.2 3.4 -71.4	149.6 3.4 -71.3	153.0 3.4 -71.3	156.4 3.4 -71.3	159.8 3.4 -71.3	163.2 3.4 -71.3	166.6 3.4 -71.3	170.1 3.4 -71.3
32----	173.5 3.5 -71.3	177.0 3.5 -71.3	180.4 3.5 -71.3	183.9 3.5 -71.3	187.4 3.5 -71.3	190.8 3.5 -71.3	194.3 3.5 -71.3	197.8 3.5 -71.3	201.3 3.5 -71.3	204.8 3.5 -71.3
33----	208.3 3.5 -71.3	211.8 3.5 -71.3	215.4 3.5 -71.3	218.9 3.5 -71.3	222.4 3.5 -71.2	226.0 3.5 -71.2	229.5 3.6 -71.2	233.1 3.6 -71.2	236.6 3.6 -71.2	240.2 3.6 -71.2
34----	243.8 3.6 -71.2	247.4 3.6 -71.2	250.9 3.6 -71.2	254.5 3.6 -71.2	258.1 3.6 -71.2	261.8 3.6 -71.2	265.4 3.6 -71.2	269.0 3.6 -71.2	272.6 3.6 -71.2	276.2 3.6 -71.2
35----	279.9 3.6 -71.2	283.5 3.7 -71.2	287.2 3.7 -71.2	290.8 3.7 -71.2	294.5 3.7 -71.2	298.2 3.7 -71.2	301.9 3.7 -71.2	305.5 3.7 -71.2	309.2 3.7 -71.1	312.9 3.7 -71.1

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ [$10^{-8}m^3/kg$] at atmospheric pressure

S = 43.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
9----	-497.9 1.7 -73.7	-496.3 1.7 -73.6	-494.6 1.7 -73.6	-492.9 1.7 -73.6	-491.2 1.7 -73.6	-489.5 1.7 -73.6	-487.7 1.7 -73.6	-486.0 1.7 -73.5	-484.3 1.8 -73.5	-482.5 1.8 -73.5
10----	-480.7 1.8 -73.5	-479.0 1.8 -73.5	-477.2 1.8 -73.5	-475.4 1.8 -73.4	-473.6 1.8 -73.4	-471.8 1.8 -73.4	-470.0 1.8 -73.4	-468.2 1.8 -73.4	-466.3 1.8 -73.4	-464.5 1.9 -73.3
11----	-462.6 1.9 -73.3	-460.8 1.9 -73.3	-458.9 1.9 -73.3	-457.0 1.9 -73.3	-455.2 1.9 -73.3	-453.3 1.9 -73.2	-451.4 1.9 -73.2	-449.4 1.9 -73.2	-447.5 1.9 -73.2	-445.6 1.9 -73.2
12----	-443.7 1.9 -73.2	-441.7 2.0 -73.1	-439.8 2.0 -73.1	-437.8 2.0 -73.1	-435.8 2.0 -73.1	-433.8 2.0 -73.1	-431.8 2.0 -73.1	-429.8 2.0 -73.1	-427.8 2.0 -73.0	-425.8 2.0 -73.0
13----	-423.8 2.0 -73.0	-421.8 2.0 -73.0	-419.7 2.0 -73.0	-417.7 2.1 -73.0	-415.6 2.1 -73.0	-413.6 2.1 -72.9	-411.5 2.1 -72.9	-409.4 2.1 -72.9	-407.3 2.1 -72.9	-405.2 2.1 -72.9
14----	-403.1 2.1 -72.9	-401.0 2.1 -72.9	-398.8 2.1 -72.8	-396.7 2.1 -72.8	-394.6 2.2 -72.8	-392.4 2.2 -72.8	-390.3 2.2 -72.8	-388.1 2.2 -72.8	-385.9 2.2 -72.8	-383.7 2.2 -72.7
15----	-381.5 2.2 -72.7	-379.3 2.2 -72.7	-377.1 2.2 -72.7	-374.9 2.2 -72.7	-372.7 2.2 -72.7	-370.5 2.2 -72.7	-368.2 2.2 -72.7	-366.0 2.3 -72.6	-363.7 2.3 -72.6	-361.4 2.3 -72.6
16----	-359.2 2.3 -72.6	-356.9 2.3 -72.6	-354.6 2.3 -72.6	-352.3 2.3 -72.6	-350.0 2.3 -72.6	-347.7 2.3 -72.5	-345.3 2.3 -72.5	-343.0 2.3 -72.5	-340.7 2.3 -72.5	-338.3 2.4 -72.5
17----	-336.0 2.4 -72.5	-333.6 2.4 -72.5	-331.2 2.4 -72.5	-328.9 2.4 -72.4	-326.5 2.4 -72.4	-324.1 2.4 -72.4	-321.7 2.4 -72.4	-319.3 2.4 -72.4	-316.9 2.4 -72.4	-314.4 2.4 -72.4
18----	-312.0 2.4 -72.4	-309.5 2.5 -72.4	-307.1 2.5 -72.3	-304.6 2.5 -72.3	-302.2 2.5 -72.3	-299.7 2.5 -72.3	-297.2 2.5 -72.3	-294.7 2.5 -72.3	-292.2 2.5 -72.3	-289.7 2.5 -72.3
19----	-287.2 2.5 -72.3	-284.7 2.5 -72.2	-282.2 2.5 -72.2	-279.6 2.5 -72.2	-277.1 2.6 -72.2	-274.5 2.6 -72.2	-272.0 2.6 -72.2	-269.4 2.6 -72.2	-266.8 2.6 -72.2	-264.3 2.6 -72.2
20----	-261.7 2.6 -72.1	-259.1 2.6 -72.1	-256.5 2.6 -72.1	-253.8 2.6 -72.1	-251.2 2.6 -72.1	-248.6 2.6 -72.1	-246.0 2.6 -72.1	-243.3 2.7 -72.1	-240.7 2.7 -72.1	-238.0 2.7 -72.1
21----	-235.3 2.7 -72.0	-232.7 2.7 -72.0	-230.0 2.7 -72.0	-227.3 2.7 -72.0	-224.6 2.7 -72.0	-221.9 2.7 -72.0	-219.2 2.7 -72.0	-216.5 2.7 -72.0	-213.7 2.7 -72.0	-211.0 2.7 -72.0

Table III (cont.)

Specific volume anomaly, $\delta(S, t, 0)$ [$10^{-8}m^3/kg$] at atmospheric pressure

S = 43.0

T	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
22----	-208.3 2.7 -72.0	-205.5 2.8 -71.9	-202.8 2.8 -71.9	-200.0 2.8 -71.9	-197.2 2.8 -71.9	-194.4 2.8 -71.9	-191.7 2.8 -71.9	-188.9 2.8 -71.9	-186.1 2.8 -71.9	-183.3 2.8 -71.9
23----	-180.4 2.8 -71.9	-177.6 2.8 -71.9	-174.8 2.8 -71.8	-172.0 2.8 -71.8	-169.1 2.9 -71.8	-166.3 2.9 -71.8	-163.4 2.9 -71.8	-160.5 2.9 -71.8	-157.7 2.9 -71.8	-154.8 2.9 -71.8
24----	-151.9 2.9 -71.8	-149.0 2.9 -71.8	-146.1 2.9 -71.8	-143.2 2.9 -71.8	-140.2 2.9 -71.7	-137.3 2.9 -71.7	-134.4 2.9 -71.7	-131.4 2.9 -71.7	-128.5 3.0 -71.7	-125.5 3.0 -71.7
25----	-122.6 3.0 -71.7	-119.6 3.0 -71.7	-116.6 3.0 -71.7	-113.7 3.0 -71.7	-110.7 3.0 -71.7	-107.7 3.0 -71.7	-104.7 3.0 -71.7	-101.6 3.0 -71.6	-98.6 3.0 -71.6	-95.6 3.0 -71.6
26----	-92.6 3.0 -71.6	-89.5 3.0 -71.6	-86.5 3.1 -71.6	-83.4 3.1 -71.6	-80.4 3.1 -71.6	-77.3 3.1 -71.6	-74.2 3.1 -71.6	-71.1 3.1 -71.6	-68.0 3.1 -71.6	-64.9 3.1 -71.6
27----	-61.8 3.1 -71.6	-58.7 3.1 -71.5	-55.6 3.1 -71.5	-52.5 3.1 -71.5	-49.3 3.1 -71.5	-46.2 3.1 -71.5	-43.1 3.2 -71.5	-39.9 3.2 -71.5	-36.7 3.2 -71.5	-33.6 3.2 -71.5
28----	-30.4 3.2 -71.5	-27.2 3.2 -71.5	-24.0 3.2 -71.5	-20.8 3.2 -71.5	-17.6 3.2 -71.5	-14.4 3.2 -71.5	-11.2 3.2 -71.4	-8.0 3.2 -71.4	-4.7 3.2 -71.4	-1.5 3.2 -71.4
29----	1.7 3.3 -71.4	5.0 3.3 -71.4	8.3 3.3 -71.4	11.5 3.3 -71.4	14.8 3.3 -71.4	18.1 3.3 -71.4	21.4 3.3 -71.4	24.6 3.3 -71.4	27.9 3.3 -71.4	31.3 3.3 -71.4
30----	34.6 3.3 -71.4	37.9 3.3 -71.4	41.2 3.3 -71.4	44.5 3.3 -71.3	47.9 3.3 -71.3	51.2 3.4 -71.3	54.6 3.4 -71.3	58.0 3.4 -71.3	61.3 3.4 -71.3	64.7 3.4 -71.3
31----	68.1 3.4 -71.3	71.5 3.4 -71.3	74.9 3.4 -71.3	78.3 3.4 -71.3	81.7 3.4 -71.3	85.1 3.4 -71.3	88.5 3.4 -71.3	91.9 3.4 -71.3	95.4 3.4 -71.3	98.8 3.4 -71.3
32----	102.3 3.5 -71.3	105.7 3.5 -71.2	109.2 3.5 -71.2	112.6 3.5 -71.2	116.1 3.5 -71.2	119.6 3.5 -71.2	123.1 3.5 -71.2	126.6 3.5 -71.2	130.1 3.5 -71.2	133.6 3.5 -71.2
33----	137.1 3.5 -71.2	140.6 3.5 -71.2	144.2 3.5 -71.2	147.7 3.5 -71.2	151.2 3.5 -71.2	154.8 3.6 -71.2	158.3 3.6 -71.2	161.9 3.6 -71.2	165.5 3.6 -71.2	169.0 3.6 -71.2
34----	172.6 3.6 -71.2	176.2 3.6 -71.2	179.8 3.6 -71.2	183.4 3.6 -71.1	187.0 3.6 -71.1	190.6 3.6 -71.1	194.2 3.6 -71.1	197.9 3.6 -71.1	201.5 3.6 -71.1	205.1 3.6 -71.1
35----	208.8 3.7 -71.1	212.4 3.7 -71.1	216.1 3.7 -71.1	219.7 3.7 -71.1	223.4 3.7 -71.1	227.1 3.7 -71.1	230.8 3.7 -71.1	234.5 3.7 -71.1	238.1 3.7 -71.1	241.8 3.7 -71.1

Table VI

Salinity-pressure correction, $\delta(S, 0, p) - \delta(S, 0, 0)$ [$10^{-8} m^3/kg$]

Pressure (dbar)	Salinity			
	40.0	41.0	42.0	43.0
0----	0.0	0.0	0.0	0.0
100----	0.7	0.9	1.0	1.2
200----	1.5	1.8	2.1	2.4
300----	2.2	2.7	3.1	3.5
400----	3.0	3.5	4.1	4.7
500----	3.7	4.4	5.1	5.9
600----	4.4	5.3	6.1	7.0
700----	5.1	6.2	7.2	8.2
800----	5.9	7.0	8.2	9.3
900----	6.6	7.9	9.2	10.4
1000----	7.3	8.7	10.2	11.6
1100----	8.0	9.6	11.1	12.7
1200----	8.7	10.4	12.1	13.8
1300----	9.4	11.3	13.1	15.0
1400----	10.1	12.1	14.1	16.1
1500----	10.8	13.0	15.1	17.2
1600----	11.5	13.8	16.0	18.3
1700----	12.2	14.6	17.0	19.4
1800----	12.9	15.4	18.0	20.5
1900----	13.6	16.3	18.9	21.6
2000----	14.3	17.1	19.9	22.7
2500----	17.6	21.1	24.6	28.0
3000----	20.9	25.1	29.2	33.3
3500----	24.2	28.9	33.7	38.4
4000----	27.3	32.7	38.1	43.4

Table VII

Table VIII (a-c)

Thermal expansibility coefficient $10^7 \alpha = -10^7(1/\rho)(\partial\rho/\partial t)$ [1/°C]

0 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
5.0----	1257	1281	1305	1328
6.0----	1364	1387	1410	1432
7.0----	1468	1490	1512	1533
8.0----	1570	1591	1611	1632
9.0----	1669	1689	1709	1729
10.0----	1765	1785	1804	1823
11.0----	1860	1879	1897	1915
12.0----	1953	1971	1988	2006
13.0----	2044	2061	2077	2094
14.0----	2133	2149	2165	2181
15.0----	2220	2236	2251	2267
16.0----	2306	2321	2336	2351
17.0----	2390	2405	2419	2433
18.0----	2473	2487	2501	2514
19.0----	2555	2568	2581	2594
20.0----	2636	2648	2661	2673
21.0----	2715	2727	2739	2751
22.0----	2793	2805	2816	2828
23.0----	2870	2881	2893	2904
24.0----	2946	2957	2968	2979
25.0----	3022	3032	3042	3052
26.0----	3096	3106	3116	3125
27.0----	3169	3179	3188	3198
28.0----	3241	3251	3260	3269
29.0----	3313	3322	3330	3339
30.0----	3383	3392	3400	3408
31.0----	3453	3461	3469	3477
32.0----	3521	3529	3537	3545
33.0----	3589	3596	3604	3611
34.0----	3655	3662	3670	3677
35.0----	3721	3728	3734	3741

1000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	2739	2751	2762	2774
21.0----	2813	2824	2835	2846
22.0----	2886	2896	2907	2918
23.0----	2957	2968	2978	2988
24.0----	3028	3038	3048	3058
25.0----	3099	3108	3118	3127

2000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	2838	2849	2860	2871
21.0----	2907	2917	2927	2938
22.0----	2974	2984	2994	3004
23.0----	3041	3051	3060	3070
24.0----	3107	3117	3126	3135
25.0----	3173	3182	3190	3199

3000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	2933	2943	2953	2963
21.0----	2997	3006	3016	3025
22.0----	3059	3069	3078	3087
23.0----	3122	3130	3139	3148
24.0----	3183	3192	3200	3208
25.0----	3244	3252	3260	3268

Table IX Table X (a-c)

Salinity "contraction" coefficient $10^7\ \beta = +10^7(1/\rho)(\partial\rho/\partial S)$

0 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
5.0----	7702	7700	7697	7695
6.0----	7679	7676	7674	7672
7.0----	7656	7654	7652	7650
8.0----	7635	7633	7631	7629
9.0----	7614	7612	7610	7608
10.0----	7595	7593	7591	7589
11.0----	7576	7574	7572	7570
12.0----	7557	7556	7554	7552
13.0----	7540	7538	7537	7535
14.0----	7523	7522	7520	7519
15.0----	7507	7506	7505	7503
16.0----	7492	7491	7489	7488
17.0----	7477	7476	7475	7474
18.0----	7463	7462	7461	7460
19.0----	7450	7449	7448	7447
20.0----	7437	7436	7435	7434
21.0----	7425	7423	7422	7422
22.0----	7413	7412	7411	7410
23.0----	7401	7400	7399	7398
24.0----	7390	7389	7388	7388
25.0----	7380	7379	7378	7377
26.0----	7369	7369	7368	7367
27.0----	7360	7359	7358	7357
28.0----	7350	7350	7349	7348
29.0----	7341	7341	7340	7339
30.0----	7333	7332	7331	7331
31.0----	7324	7324	7323	7323
32.0----	7317	7316	7315	7315
33.0----	7309	7308	7308	7307
34.0----	7302	7301	7300	7300
35.0----	7295	7294	7293	7293

1000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	7352	7352	7351	7350
21.0----	7341	7340	7339	7339
22.0----	7330	7329	7328	7328
23.0----	7319	7318	7318	7317
24.0----	7309	7308	7308	7307
25.0----	7299	7299	7298	7298

2000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	7271	7270	7270	7269
21.0----	7260	7260	7259	7259
22.0----	7250	7249	7249	7249
23.0----	7240	7240	7239	7239
24.0----	7231	7230	7230	7230
25.0----	7222	7221	7221	7221

3000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	7192	7192	7191	7191
21.0----	7182	7182	7182	7182
22.0----	7173	7172	7172	7172
23.0----	7164	7163	7163	7163
24.0----	7155	7155	7155	7155
25.0----	7147	7147	7147	7147

Table XI

Table XII

Isothermal compressibility coefficient $10^7 k = +10^7(1/\rho)(\partial\rho/\partial p)$ [1/dbar]

0 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
5.0----	44.5	44.4	44.3	44.2
6.0----	44.3	44.2	44.1	44.0
7.0----	44.1	44.0	43.9	43.8
8.0----	43.9	43.8	43.7	43.6
9.0----	43.7	43.6	43.5	43.4
10.0----	43.6	43.5	43.4	43.3
11.0----	43.4	43.3	43.2	43.1
12.0----	43.2	43.1	43.0	43.0
13.0----	43.1	43.0	42.9	42.8
14.0----	42.9	42.8	42.8	42.7
15.0----	42.8	42.7	42.6	42.5
16.0----	42.7	42.6	42.5	42.4
17.0----	42.5	42.4	42.4	42.3
18.0----	42.4	42.3	42.2	42.2
19.0----	42.3	42.2	42.1	42.0
20.0----	42.2	42.1	42.0	41.9
21.0----	42.1	42.0	41.9	41.8
22.0----	42.0	41.9	41.8	41.7
23.0----	41.9	41.8	41.7	41.7
24.0----	41.8	41.7	41.7	41.6
25.0----	41.7	41.7	41.6	41.5
26.0----	41.7	41.6	41.5	41.4
27.0----	41.6	41.5	41.4	41.3
28.0----	41.5	41.4	41.4	41.3
29.0----	41.5	41.4	41.3	41.2
30.0----	41.4	41.3	41.2	41.2
31.0----	41.4	41.3	41.2	41.1
32.0----	41.3	41.2	41.1	41.1
33.0----	41.3	41.2	41.1	41.0
34.0----	41.2	41.1	41.1	41.0
35.0----	41.2	41.1	41.0	41.0

2000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	40.2	40.1	40.0	40.0
21.0----	40.1	40.0	39.9	39.9
22.0----	40.0	39.9	39.9	39.8
23.0----	39.9	39.9	39.8	39.7
24.0----	39.8	39.8	39.7	39.6
25.0----	39.8	39.7	39.6	39.5

Table XIII Table XIV

Isopycnal derivative, $(\partial S/\partial t)_\rho$

0 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
5.0----	.1633	.1664	.1696	.1727
6.0----	.1777	.1807	.1837	.1867
7.0----	.1918	.1947	.1976	.2005
8.0----	.2056	.2084	.2112	.2140
9.0----	.2192	.2219	.2246	.2273
10.0----	.2325	.2351	.2377	.2403
11.0----	.2456	.2481	.2506	.2530
12.0----	.2584	.2609	.2632	.2656
13.0----	.2711	.2734	.2757	.2780
14.0----	.2835	.2857	.2879	.2901
15.0----	.2958	.2979	.3000	.3021
16.0----	.3078	.3099	.3119	.3139
17.0----	.3197	.3217	.3236	.3256
18.0----	.3314	.3333	.3352	.3371
19.0----	.3430	.3448	.3466	.3485
20.0----	.3544	.3562	.3579	.3597
21.0----	.3657	.3674	.3691	.3707
22.0----	.3768	.3785	.3801	.3817
23.0----	.3879	.3894	.3910	.3925
24.0----	.3987	.4002	.4017	.4032
25.0----	.4095	.4109	.4124	.4138
26.0----	.4201	.4215	.4229	.4243
27.0----	.4306	.4320	.4333	.4346
28.0----	.4410	.4423	.4436	.4449
29.0----	.4513	.4525	.4538	.4550
30.0----	.4614	.4626	.4638	.4650
31.0----	.4714	.4726	.4737	.4749
32.0----	.4813	.4824	.4835	.4846
33.0----	.4911	.4921	.4932	.4942
34.0----	.5007	.5017	.5027	.5037
35.0----	.5101	.5111	.5121	.5130

1000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	.3726	.3742	.3758	.3775
21.0----	.3832	.3848	.3863	.3879
22.0----	.3937	.3952	.3967	.3982
23.0----	.4041	.4056	.4070	.4085
24.0----	.4144	.4158	.4172	.4186
25.0----	.4246	.4259	.4272	.4286

2000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	.3904	.3919	.3934	.3949
21.0----	.4004	.4019	.4033	.4048
22.0----	.4103	.4117	.4131	.4145
23.0----	.4201	.4214	.4228	.4241
24.0----	.4298	.4311	.4324	.4336
25.0----	.4394	.4406	.4418	.4431

3000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	.4079	.4093	.4107	.4121
21.0----	.4173	.4186	.4200	.4213
22.0----	.4266	.4279	.4292	.4304
23.0----	.4358	.4370	.4383	.4395
24.0----	.4449	.4461	.4473	.4485
25.0----	.4539	.4551	.4562	.4573

Table XVI — Table XVII (a-c)

Adiabatic lapse rate, (Γ) [°C/1000 dbar]

0 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
5.0----	.0857	.0874	.0891	.0907
6.0----	.0933	.0949	.0966	.0982
7.0----	.1008	.1024	.1039	.1055
8.0----	.1082	.1097	.1112	.1127
9.0----	.1154	.1169	.1183	.1198
10.0----	.1225	.1239	.1253	.1267
11.0----	.1295	.1309	.1323	.1336
12.0----	.1365	.1378	.1391	.1404
13.0----	.1433	.1446	.1458	.1471
14.0----	.1501	.1513	.1525	.1537
15.0----	.1567	.1579	.1591	.1603
16.0----	.1634	.1645	.1657	.1668
17.0----	.1699	.1710	.1721	.1732
18.0----	.1764	.1775	.1786	.1796
19.0----	.1829	.1839	.1850	.1860
20.0----	.1893	.1903	.1913	.1923
21.0----	.1957	.1966	.1976	.1986
22.0----	.2020	.2029	.2039	.2048
23.0----	.2083	.2092	.2101	.2110
24.0----	.2145	.2154	.2163	.2172
25.0----	.2208	.2216	.2225	.2233
26.0----	.2270	.2278	.2286	.2295
27.0----	.2332	.2340	.2348	.2356
28.0----	.2393	.2401	.2409	.2417
29.0----	.2454	.2462	.2469	.2477
30.0----	.2515	.2523	.2530	.2537
31.0----	.2576	.2583	.2590	.2597
32.0----	.2636	.2643	.2650	.2657
33.0----	.2696	.2703	.2710	.2717
34.0----	.2756	.2762	.2769	.2776

1000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	0.1970	0.1979	0.1989	0.1998
21.0----	0.2030	0.2039	0.2048	0.2057
22.0----	0.2090	0.2098	0.2107	0.2116
23.0----	0.2149	0.2157	0.2166	0.2174
24.0----	0.2208	0.2216	0.2224	0.2233
25.0----	0.2267	0.2275	0.2283	0.2291

2000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	0.2044	0.2052	0.2061	0.2070
21.0----	0.2100	0.2108	0.2117	0.2125
22.0----	0.2156	0.2164	0.2172	0.2181
23.0----	0.2212	0.2220	0.2228	0.2236
24.0----	0.2268	0.2275	0.2283	0.2291
25.0----	0.2323	0.2331	0.2338	0.2346

3000 dbar

Temp. °C	Salinity 40.0	41.0	42.0	43.0
20.0----	0.2114	0.2122	0.2130	0.2138
21.0----	0.2167	0.2175	0.2182	0.2190
22.0----	0.2220	0.2227	0.2235	0.2242
23.0----	0.2272	0.2280	0.2287	0.2294
24.0----	0.2325	0.2332	0.2339	0.2346
25.0----	0.2377	0.2384	0.2391	0.2398

$\Theta(35,t,p,0)$ adiabatic cooling for seawater raised to surface [°C]

PRESSURE	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0
200----	14.970	15.968	16.967	17.966	18.964	19.963	20.962	21.960	22.959	23.958	24.957	25.955	26.954	27.953	28.952
400----	14.939	15.936	16.934	17.931	18.928	19.926	20.923	21.921	22.918	23.915	24.913	25.910	26.908	27.906	28.903
600----	14.908	15.904	16.900	17.896	18.892	19.888	20.884	21.880	22.877	23.873	24.869	25.865	26.862	27.858	28.854
800----	14.877	15.871	16.866	17.861	18.856	19.850	20.845	21.840	22.835	23.830	24.825	25.820	26.815	27.810	28.805
1000----	14.845	15.838	16.832	17.825	18.819	19.812	20.806	21.800	22.793	23.787	24.781	25.775	26.769	27.763	28.757
1200----	14.813	15.805	16.797	17.789	18.782	19.774	20.766	21.759	22.751	23.744	24.737	25.729	26.722	27.715	28.707
1400----	14.780	15.771	16.762	17.753	18.744	19.735	20.727	21.718	22.709	23.701	24.692	25.683	26.675	27.667	28.658
1600----	14.748	15.737	16.727	17.717	18.706	19.696	20.686	21.677	22.667	23.657	24.647	25.638	26.628	27.618	28.609
1800----	14.714	15.703	16.691	17.680	18.669	19.657	20.646	21.635	22.624	23.613	24.602	25.591	26.581	27.570	28.559
2000----	14.681	15.668	16.655	17.643	18.630	19.618	20.606	21.593	22.581	23.569	24.557	25.545	26.533	27.521	28.510
2200----	14.647	15.633	16.619	17.605	18.592	19.578	20.565	21.551	22.538	23.525	24.512	25.499	26.486	27.473	28.460
2400----	14.613	15.598	16.583	17.568	18.553	19.538	20.524	21.509	22.495	23.481	24.466	25.452	26.438	27.424	28.410
2600----	14.579	15.562	16.546	17.530	18.514	19.498	20.483	21.467	22.451	23.436	24.421	25.405	26.390	27.375	28.360
2800----	14.544	15.526	16.509	17.492	18.475	19.458	20.441	21.424	22.408	23.391	24.375	25.358	26.342	27.326	28.310
3000----	14.509	15.490	16.472	17.453	18.435	19.417	20.399	21.382	22.364	23.346	24.329	25.311	26.294	27.277	28.260

$\Theta(35,t,0,p)$ adiabatic heating for seawater sunk from the surface [°C]

PRESSURE	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0
200----	15.030	16.032	17.033	18.034	19.036	20.037	21.038	22.040	23.041	24.042	25.043	26.045	27.046	28.047	29.048
400----	15.061	16.064	17.067	18.069	19.072	20.074	21.077	22.080	23.082	24.085	25.087	26.090	27.092	28.095	29.097
600----	15.092	16.096	17.100	18.104	19.108	20.112	21.116	22.120	23.124	24.128	25.131	26.135	27.139	28.143	29.146
800----	15.124	16.129	17.135	18.140	19.145	20.150	21.156	22.161	23.166	24.171	25.176	26.181	27.186	28.191	29.195
1000----	15.156	16.163	17.169	18.176	19.182	20.189	21.195	22.202	23.208	24.214	25.220	26.227	27.233	28.239	29.245
1200----	15.189	16.197	17.205	18.212	19.220	20.228	21.235	22.243	23.250	24.258	25.265	26.273	27.280	28.287	29.295
1400----	15.222	16.231	17.240	18.249	19.258	20.267	21.276	22.285	23.293	24.302	25.311	26.319	27.328	28.336	29.345
1600----	15.255	16.266	17.276	18.286	19.297	20.307	21.317	22.327	23.337	24.346	25.356	26.366	27.376	28.385	29.395
1800----	15.289	16.301	17.312	18.324	19.335	20.347	21.358	22.369	23.380	24.391	25.402	26.413	27.424	28.435	29.445
2000----	15.323	16.336	17.349	18.362	19.374	20.387	21.399	22.412	23.424	24.436	25.448	26.460	27.472	28.484	29.496
2200----	15.358	16.372	17.386	18.400	19.414	20.428	21.441	22.455	23.468	24.481	25.495	26.508	27.521	28.534	29.547
2400----	15.393	16.408	17.424	18.439	19.454	20.468	21.483	22.498	23.512	24.527	25.541	26.556	27.570	28.584	29.598
2600----	15.428	16.445	17.461	18.478	19.494	20.510	21.526	22.541	23.557	24.573	25.588	26.604	27.619	28.635	29.650
2800----	15.464	16.482	17.500	18.517	19.534	20.551	21.568	22.585	23.602	24.619	25.636	26.652	27.669	28.685	29.702
3000----	15.501	16.519	17.538	18.557	19.575	20.593	21.612	22.630	23.647	24.665	25.683	26.701	27.718	28.736	29.753

Table XIX

$\Delta\Theta_1(S, 0, p, 0)$ [°C] for S ≠ 35 versus pressure

Pressure (dbar)	Salinity 40.0	41.0	42.0	43.0
200----	-0.002	-0.002	-0.003	-0.003
400----	-0.004	-0.004	-0.005	-0.006
600----	-0.006	-0.007	-0.008	-0.009
800----	-0.007	-0.009	-0.010	-0.012
1000----	-0.009	-0.011	-0.013	-0.015
1200----	-0.011	-0.013	-0.015	-0.017
1400----	-0.013	-0.015	-0.018	-0.020
1600----	-0.014	-0.017	-0.020	-0.023
1800----	-0.016	-0.019	-0.022	-0.026
2000----	-0.018	-0.021	-0.025	-0.028
2200----	-0.019	-0.023	-0.027	-0.031
2400----	-0.021	-0.025	-0.029	-0.033
2600----	-0.023	-0.027	-0.032	-0.036
2800----	-0.024	-0.029	-0.034	-0.039
3000----	-0.026	-0.031	-0.036	-0.041

Table XX

$\Delta\Theta_2(S, t, 10000, 0)$ [°C] temperature versus salinity

Temp. °C	Salinity 30.0	31.0	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0
15.0 ----	-0.020	-0.016	-0.012	-0.008	-0.004	0.000	0.004	0.008	0.012	0.016	0.020	0.024	0.028	0.032
16.0 ----	-0.021	-0.017	-0.013	-0.009	-0.004	0.000	0.004	0.009	0.013	0.017	0.021	0.026	0.030	0.034
17.0 ----	-0.023	-0.018	-0.014	-0.009	-0.005	0.000	0.005	0.009	0.014	0.018	0.023	0.027	0.032	0.036
18.0 ----	-0.024	-0.019	-0.014	-0.010	-0.005	0.000	0.005	0.010	0.014	0.019	0.024	0.029	0.034	0.039
19.0 ----	-0.025	-0.020	-0.015	-0.010	-0.005	0.000	0.005	0.010	0.015	0.020	0.025	0.031	0.036	0.041
20.0 ----	-0.027	-0.021	-0.016	-0.011	-0.005	0.000	0.005	0.011	0.016	0.021	0.027	0.032	0.037	0.043
21.0 ----	-0.028	-0.022	-0.017	-0.011	-0.006	0.000	0.006	0.011	0.017	0.023	0.028	0.034	0.039	0.045
22.0 ----	-0.029	-0.024	-0.018	-0.012	-0.006	0.000	0.006	0.012	0.018	0.024	0.029	0.035	0.041	0.047
23.0 ----	-0.031	-0.025	-0.018	-0.012	-0.006	0.000	0.006	0.012	0.019	0.025	0.031	0.037	0.043	0.049
24.0 ----	-0.032	-0.026	-0.019	-0.013	-0.006	0.000	0.006	0.013	0.019	0.026	0.032	0.039	0.045	0.052
25.0 ----	-0.033	-0.027	-0.020	-0.013	-0.007	0.000	0.007	0.013	0.020	0.027	0.034	0.040	0.047	0.054
26.0 ----	-0.035	-0.028	-0.021	-0.014	-0.007	0.000	0.007	0.014	0.021	0.028	0.035	0.042	0.049	0.056
27.0 ----	-0.036	-0.029	-0.022	-0.014	-0.007	0.000	0.007	0.015	0.022	0.029	0.036	0.044	0.051	0.058
28.0 ----	-0.038	-0.030	-0.023	-0.015	-0.008	0.000	0.008	0.015	0.023	0.030	0.038	0.045	0.053	0.060
29.0 ----	-0.039	-0.031	-0.023	-0.016	-0.008	0.000	0.008	0.016	0.023	0.031	0.039	0.047	0.055	0.062
30.0 ----	-0.040	-0.032	-0.024	-0.016	-0.008	0.000	0.008	0.016	0.024	0.032	0.040	0.048	0.056	0.065
31.0 ----	-0.042	-0.033	-0.025	-0.017	-0.008	0.000	0.008	0.017	0.025	0.033	0.042	0.050	0.058	0.067
32.0 ----	-0.043	-0.034	-0.026	-0.017	-0.009	0.000	0.009	0.017	0.026	0.034	0.043	0.052	0.060	0.069

Table XXVII (b)

Salinity as a function of density anomaly, $\gamma(S, t, 2000)$

2000 dbar

Temp. °C	Density anomaly										
	37.50	38.00	38.50	39.00	39.50	40.00	40.50	41.00	41.50	42.00	42.50
15.0----	38.725	39.382	40.038	40.695	41.351	42.007	42.663	43.319	43.974	44.629	45.283
16.0----	39.066	39.725	40.383	41.040	41.698	42.355	43.012	43.669	44.325	44.981	45.637
17.0----	39.419	40.079	40.738	41.397	42.056	42.714	43.372	44.030	44.687	45.345	46.002
18.0----	39.784	40.444	41.105	41.765	42.424	43.084	43.743	44.402	45.060	45.719	46.377
19.0----	40.159	40.820	41.482	42.143	42.804	43.464	44.124	44.784	45.444	46.103	46.762
20.0----	40.545	41.207	41.870	42.532	43.194	43.855	44.516	45.177	45.838	46.498	47.158
21.0----	40.941	41.605	42.268	42.931	43.594	44.256	44.919	45.581	46.242	46.903	47.564
22.0----	41.348	42.013	42.677	43.341	44.005	44.668	45.331	45.994	46.657	47.319	47.981
23.0----	41.765	42.431	43.096	43.761	44.426	45.090	45.754	46.418	47.081	47.744	48.407
24.0----	42.193	42.859	43.525	44.191	44.857	45.522	46.187	46.851	47.515	48.179	48.843
25.0----	42.631	43.298	43.965	44.631	45.298	45.964	46.629	47.295	47.960	48.624	49.289

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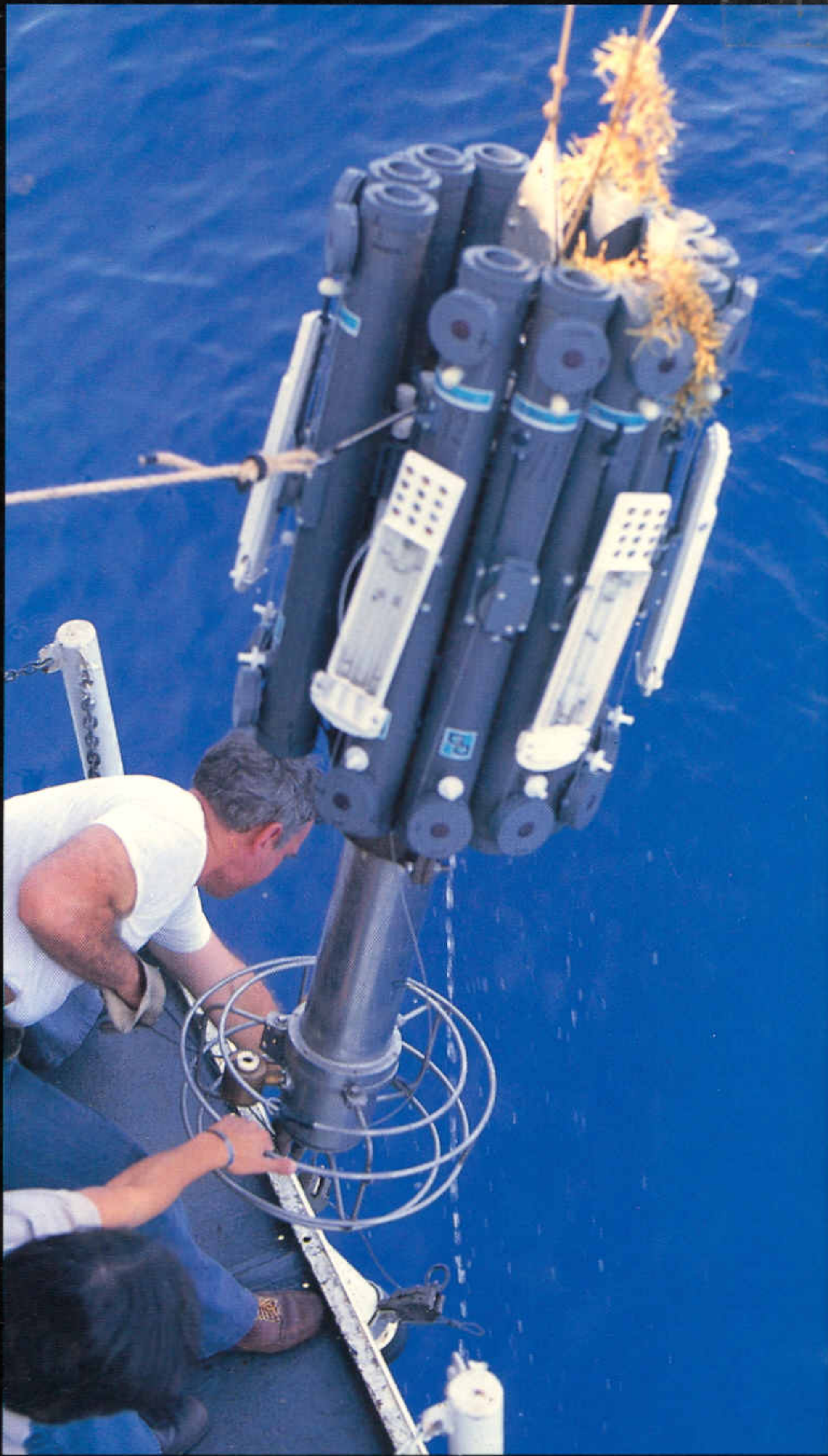

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ISBN 92-3-102756-5