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SEAWATER

A Library of MATLAB® Computational Routines for the Properties of Sea Water

Version 1.2

Phillip P. Morgan

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AUSTRALIA

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CONTENTS

Preface

Scope of Document

This document describes how you can use the SEAWATER library of routines to calculate properties of sea water. The library is implemented in the MATLAB® language version 4. It is assumed you are familiar with physical oceanography and only a novice user of MATLAB or other programming languages. SEAWATER is essentially a computational package for oceanographers who may have little experience in using programming languages.

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Acknowledgments

Thanks to Dr Steve Rintoul for granting the time and resources to develop this library; to Dr Nathan Bindoff for supplying the routines sw_alpha, sw_beta and sw_aonb, and to Drs David Jackett and John Wilkin for direction with sw_bfrq.

This work contributes to the CSIRO Climate Change Research Program, and is funded in part by Australia's National Greenhouse Research Program.

Errors and Suggestions

To uphold the integrity of the library, please report all errors and suggestions to me at the address below so that I can update the master set. When reporting errors, please record an actual session (use the diary command in MATLAB).

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1 Introduction

Many scientists have realised the value of "Fourth Generation Languages" such as MATLAB for carrying out data analysis. These languages enable scientists to concentrate on conducting research without worrying about the more technical aspects of computing.

SEAWATER is a library of MATLAB computational routines for determining properties of sea water that are commonly used in oceanographic research. It is of the utmost importance that these determinations are accurate. The driving force for developing this library was the need for an easy to use, set of routines that had been thoroughly tested. The SEAWATER library can be used on any computer platform that supports MATLAB. No recompiling or conversion is necessary.

MATLAB automatically keeps track of missing or bad data with the Not-A-Number (NaN) feature, and the ability to use multidimensional data structures in calculations greatly adds to the simplicity and usefulness of the library. For example, it is a simple matter to calculate the density for an entire hydrographic section (salinity, temperature and pressure) that has missing/bad data in a one-line statement, by calling the SEAWATER library.

The SEAWATER library implements all the polynomial equations presented by Foffonoff and Millard (UNESCO 1983). Validation of the SEAWATER library against the UNESCO results is demonstrated in Appendix C. A number of additional oceanographic properties, not described in the UNESCO report, are supported in the SEAWATER library and are described below.

1.1 Potential Density

Sea water is slightly compressible, which means that a sample of water brought from a depth to the surface will expand and therefore be cooler than it was in situ. The term "potential temperature" refers to the temperature of the sample of water at the surface if brought to the surface adiabatically. Similarly, "potential density" refers to the density of this water sample at the surface (Pond and Pickard 1986). The more general case is for a sample of water to be brought to a specified "reference" depth.

The potential density (ρ_θ) of sea water relative to a reference pressure (P_r) is a function of in situ salinity (S) and the potential temperature (θ), given by

$$\rho_\theta = \rho(S,\theta,P_r) \quad [\mathrm{kg\ m^{-3}}].$$

This can be calculated by passing the reference pressure and the in situ salinity, temperature and pressure to the routine sw_pden,

pden = sw_pden(S,T,P,PR).

The potential density anomaly (σ_θ) is simply given by

$$\sigma_\theta = \rho_\theta - 1000.$$

1.2 Thermal Expansion and Saline Contraction

Polynomial expressions for the thermal expansion coefficient (α) and saline contraction coefficient (β) were defined by McDougall (1987). The polynomial expressions for α, β, and α/β have been implemented in routines sw_alpha, sw_beta and sw_aonb respectively. Check values from McDougall (1987) have been included in the on-line documentation.

1.3 Gravitational Acceleration and Coriolis Factor

Gill (1982) extended the UNESCO (1983) equation for the gravitational acceleration (g) as a function of latitude (ϕ) to include the radius of the Earth (a) and the variation with depth below sea surface (z),

$$g = (9.78032+0.005172Sin^2\phi-0.00006Sin^2 2\phi)(1+z/a) \quad [\mathrm{m\ s^{-2}}].$$

The expression for the Coriolis factor (f) is defined in Pond and Pickard (1986) by

$$f = 2\Omega Sin\phi \quad [\mathrm{s^{-1}}],$$

where the rotation of the Earth is given by $\Omega=7.29\mathrm{x}10^{-5}\ \mathrm{s}^{-1}$. The routines sw_g and sw_f evaluate the above two equations.

1.4 Distance in Latitude, Longitude Coordinates

The rhumb line or plain sailing method (Gormley 1989) is used to estimate the distance (d) between two positions on the earth's surface in latitude (ϕ) and longitude (θ) coordinates by the equation

$$d = 60\sqrt{(\Delta\phi)^2+(\Delta\theta Cos\phi_{av})^2} \quad \text{[n.miles]},$$

where ϕ_{av} is the mean latitude, and the constant "60" converts to nautical mile units. The routine sw_dist can be used to evaluate distance.

1.5 Geostrophic Velocity

The concept of geostrophic velocity is well covered by Pond and Pickard (1986). The geostrophic velocity at a level (V_1) relative to a lower level (V_2) between two stations denoted by A and B is estimated by

$$V_1-V_2=\frac{(\Delta\Phi_B-\Delta\Phi_A)}{2d\Omega Sin\phi_{ave}} \quad [\text{m s}^{-1}],$$

where d is the distance between stations and the geopotential anomaly ($\Delta\Phi$) is the integral of the specific volume anomaly (δ),

$$\Delta\Phi = \int_{P_1}^{P_2}\delta\, dp \quad [\text{J kg}^{-1}].$$

If we traverse the section from station A to station B, a positive velocity is directed to the left of the path, whereas a negative velocity is directed to the right. This convention holds in both the northern and southern hemispheres, since southern latitudes span 0 to -90 degrees, which accounts for the different direction of the Coriolis force in the two hemispheres.

Evaluation of geostrophic velocities, relative to the sea surface, requires two steps in calling the SEAWATER routines:

```
gpan = sw_gpan(S,T,P)
gvel = sw_gvel(gpan,lat,lon)
```

Chapter 4 has an example of how to convert this velocity to a velocity relative to an arbitrary "reference" depth.

1.6 Buoyancy (Brunt-Väisälä) Frequency

The concept of stability is well covered by Gill (1982). The buoyancy frequency (N), also called the Brunt-Väisälä frequency, can be expressed (Jackett and McDougall, 1994) as a function of potential density (ρ_θ) by

$$N^2 = \frac{-g}{\rho_\theta}\frac{d\rho_\theta}{dz} \quad [s^{-2}].$$

The square of the buoyancy frequency is evaluated by the routine sw_bfrq.

Other methods for evaluating buoyancy frequency are discussed in (Millard et al. 1990); they are not used by the SEAWATER library.

2 Overview

2.1 Components of Library

The routines are designed to run on any computer that can run MATLAB, which includes MS-DOS PC, Mac, VAX and Unix machines. The names of routines are restricted to eight characters to be consistent with MS-DOS filename limitations. They are also prefixed by sw_, which denotes SEAWATER library routines, to delineate them from other routines that you may have. For example, the routine to calculate density is called "sw_dens.m".

The design of this library was for an extensible set of routines based on Software Engineering principles. Routine names and input parameter names are consistent, input parameters are not modified by the routines, and all routines have extensive on-line documentation and have been thoroughly tested. One advantage in this design is that the SEAWATER library forms a toolbox around which you may write further applications. This approach warrants splitting code into modules for easy development, testing and maintenance.

2.2 Brief Description of All Routines

A brief description of each routine in the SEAWATER library can be obtained by issuing the command `sw_info`.

```
ROUTINE     DESCRIPTION
-------     -----------
SW_ALPHA    Thermal expansion coefficient (alpha)
SW_ADTG     Adiabatic temperature gradient
SW_AONB     Calculate alpha/beta (a on b)
SW_BETA     Saline contraction coefficient (beta)
SW_BFRQ     Brunt-Vaisala frequency (N^2)
SW_C3515    Conductivity at (35,15,0)
SW_CNDR     Conductivity ratio   R = C(S,T,P)/C(35,15,0)
SW_CP       Heat capacity (Cp) of sea water
SW_DENS     Density of sea water
SW_DENS0    Density of sea water at atmospheric pressure
SW_DIST     Distance between two lat, lon coordinates
SW_DPTH     Depth from pressure
SW_F        Coriolis factor "f"
SW_FP       Freezing point of sea water
SW_G        Gravitational acceleration
SW_GPAN     Geopotential anomaly
```

```
SW_GVEL     Geostrophic velocity
SW_INFO     Information on the SEAWATER library.
SW_PDEN     Potential density
SW_PRES     Pressure from depth
SW_PTMP     Potential temperature
SW_SALDS    Differential dS/d(sqrt(Rt)) at constant T.
SW_SALRP    Conductivity ratio   Rp(S,T,P) = C(S,T,P)/C(S,T,0)
SW_SALRT    Conductivity ratio   rt(T) = C(35,T,0)/C(35,15,0)
SW_SALS     Salinity of sea water
SW_SALT     Salinity from cndr, T, P
SW_SECK     Secant bulk modulus (K) of sea water
SW_SVAN     Specific volume anomaly
SW_SVEL     Sound velocity of sea water
SW_SMOW     Density of standard mean ocean water (pure water)
SW_TEMP     Temperature from potential temperature
```

2.3 Units of Data

The units of all properties are clearly defined in each routine. The units of pressure and depth need special attention. Pressure (in decibars) and depth (in meters) are taken to be zero at the sea surface and positive in the interior of the ocean. The routines sw_pres and sw_depth can be used to convert between pressure and depth. If you wish to use Cartesian coordinates with x,y,z representing East, North and height above sea surface respectively, then depth = -z.

The convention used for the units of latitude are decimal degrees ranging from -90 (South) to +90 (North). The units of longitude are decimal degrees ranging from -180 (180 West) to +180 (180 East).

2.4 Special Attention to the Temperature Scale

The polynomials for the equation of state (UNESCO 1983) were derived using the International Practical Temperature Scale of 1968 (IPTS-68). All routines in the SEAWATER library also use IPTS-68. The recommended conversion from the International Temperature Scale of 1990 (ITS-90) to IPTS-68 (UNESCO 1991) is the linear relationship $T_{68} = 1.00024 x T_{90}$.

2.5 Testing Library for Accuracy

A comparison of results produced by the SEAWATER library with those tabulated by UNESCO (1983) are presented in Appendix C. It should be remembered that these routines are only valid with temperature in the range -2 to 35 °C, and salinity in the range 2 to 42 psu (UNESCO 1983).

Not all routines are explicitly provided with test results, since many routines call other (lower-level) routines. A correct result at the higher level therefore verifies the lower-level routines as well.

2.6 Call Definitions for Routines

Property	Function calling template	Units
Adiabatic Temperature Gradient	adtg = sw_adtg(sal,temp,pres)	°C db^{-1}
Saline Contraction	beta = sw_beta(salt,ptmp,pres)	psu^{-1}
Conductivity	cond = cndr*sw_c3515	mS cm^{-1}
Conductivity Ratio	cndr = sw_cndr(salt,temp,pres)	
Heat Capacity	cp = sw_cp(salt,temp,pres)	J kg^{-1} $°C^{-1}$
Density	dens = sw_dens(salt,temp,pres)	kg m^{-3}
Distance	dist = sw_dist(lat,lon)	n.miles
Depth	dpth = sw_dpth(press,lat)	meters
Freezing Point	fp = sw_fp(salt,pres)	°C (IPTS68)
Geopotential Anomaly	gpan = sw_gpan(salt,temp,press)	J kg^{-1}
Geostrophic Velocity	gvel = sw_gvel(gpan,lat,lon)	m s^{-1}
Potential Density	pden = sw_pden(salt,ptmp,pres)	kg m^{-3}
Potential Temperature	ptmp = sw_ptmp(salt,temp,pres,ref_pres)	°C
Salinity	salt = sw_salt(cond,temp,pres)	psu (PPS78)
Sigma_t	sigt = sw_dens(salt,temp,zeros(salt)) - 1000	kg m^{-3}
Specify Volume Anomaly	svan = sw_svan(dens)	m^3 kg^{-1}

3 Getting Started

The SEAWATER library is accessed within MATLAB so you will need to issue the appropriate command to start MATLAB on your system. The SEAWATER library can be installed in any directory but to see whether you have the correct access, type `sw_info` for information on the library. If you get an error message, check that you have the correct paths. See Appendix A for installation procedures.

3.1 Calling the SEAWATER routines.

Each routine in the SEAWATER library has a list of input parameters and output parameters. The general format is:

[output_parameters] = sw_?????(input_parameters),

where ????? is a placeholder for the name of the particular routine.

To call a routine you must enter data in the order specified in the help display for each command. For example, the call for sw_fp is defined in the help display as fp = sw_fp(S,P). To find the freezing point (fp) of sea water with a salinity (S) of 35.203 psu at a pressure (P) of 5.5 db is easily achieved by entering the command

```
>> fp = sw_fp(35.203,5.5)
fp =
   -1.9381
```

The convention used in this document is to show commands that you enter into MATLAB with the MATLAB prompt '>> ' as a prefix. Do not enter this prefix in your commands. The output from MATLAB will be shown on lines without this prefix. In the above example, the result is assigned to the variable called "fp" on the command line. MATLAB echoes the result to the screen as shown. The echoing of results can be disabled by ending the line with a semicolon, as in the example below where the depth (d) corresponding to a pressure of 200 db at a latitude of 45 degrees is evaluated using sw_dpth:

```
>> p   = 200.5;
>> lat = 45.5;
>> d   = sw_dpth(p,lat);  % result is d = 198.7668
```

You may assign the data to named variables such as p and lat as shown in this example before passing to routines in the SEAWATER library.

3.2 Using Multidimensional data

MATLAB uses the two-dimensional data structure called a matrix (or 2D array) to store variables. An MxN matrix contains M rows and N columns. In special cases, one or both dimensions are one. A 1xN matrix is called a row vector, Mx1 a column vector and a 1x1 matrix a scalar. The SEAWATER library is designed to handle all of these data structures.

For example, if we wish to find the corresponding freezing point for sea water at salinities 35.1, 35.2 and 35.3 at pressures of 10, 20 and 30 db respectively, it is a simple matter of defining the data and calling the routine:

```
>> s = [35.1 35.2 35.3];
>> p = [10 20 30];
>> fp = sw_fp(s,p)
fp =
   -1.9356   -1.9488   -1.9621
```

Generally, the input variables need to have the same dimensions, but there are some convenient alternatives that are described in the documentation for each routine. Pressure is often a parameter that has more flexible shape constraints. An example is evaluating the freezing point of sea water at the sea surface over a range of salinities from 33 to 36 psu at increments of 0.1 psu:

```
>> s  = [33:0.1:36];
>> p  = 0;
>> fp = sw_fp(s,p)
fp =
  Columns 1 through 7
   -1.8079   -1.8136   -1.8193   -1.8250   -1.8307   -1.8364
-1.8421   Columns 8 through 14
   -1.8479   -1.8536   -1.8593   -1.8650   -1.8707   -1.8764
-1.8822   Columns 15 through 21
   -1.8879   -1.8936   -1.8994   -1.9051   -1.9108   -1.9166
-1.9223   Columns 22 through 28
   -1.9280   -1.9338   -1.9395   -1.9453   -1.9510   -1.9568
-1.9625   Columns 29 through 31
    -1.9683    -1.9741    -1.9798
```

Data in 2D arrays are just as easy to use in calculations:

```
>> s  = [35.1  35.2  35.3;
         35.0  35.1  35.2;
         34.9  35.0  35.1];
>> p  = 0
>> fp = sw_fp(s,p)
fp =
   -1.9280   -1.9338   -1.9395
   -1.9223   -1.9280   -1.9338
   -1.9166   -1.9223   -1.9280
```

4 Tutorial for Oceanographers

4.1 Data for Tutorial

In oceanography, one often needs to process data that are part of a hydrographic section which generally involves temperature and salinity measurements of sea water at various depths. A simple example of this type of data is presented in Appendix B.

A file named sw_data.mat is supplied with the SEAWATER library where the variable named "temp" and "sal" define temperature and salinity, respectively on 32 pressures at 14 stations. The locations of the 14 stations are specified in the variables "lat" and "lon". You may wish to copy this file from the installation directory to your working directory and load the data by typing the command `load sw_data` and displaying the variable names with the `whos` command, as shown:

```
>> load sw_data
>> whos
 Name          Size          Elements      Bytes     Density  Complex

bottom        1 by 14             14         112        Full       No
   lat        1 by 14             14         112        Full       No
   lon        1 by 14             14         112        Full       No
 press       32 by 1              32         256        Full       No
   sal       32 by 14            448        3584        Full       No
  temp       32 by 14            448        3584        Full       No

Grand total is 1051 elements using 8408 bytes
```

The data in the file sw_data were imported from another application wherein missing data were represented with a -99 flag in the temperature and salinity fields. To take advantage of MATLAB's automatic handling of missing data, it is necessary to convert the -99 flag to NaN. The following commands will do this:

```
ibad = find(temp<-90);
temp(ibad) = NaN*ones(size(ibad));
ibad = find(sal <-90);
sal(ibad) = NaN*ones(size(ibad));
```

Taking station number 5 as an example, the temperature and salinity profiles can be plotted and labelled (Figures 1 and 2) by using the following MATLAB commands:

```
plot(press,temp(:,5),'o')
hold on
```

```
plot(press,temp(:,5),'-')
hold off
title('Temperature Profile for Stations 5')
xlabel('Pressure (db) ')
ylabel('Temp (C) ')

plot(press,sal(:,5),'o'); hold on
plot(press,sal(:,5),'-'); hold off
title('Salinity Profile for Stations 5')
xlabel('Pressure (db) '); ylabel('Sal (psu) ')
```

Fig 1: Temperature Profile for Station 5

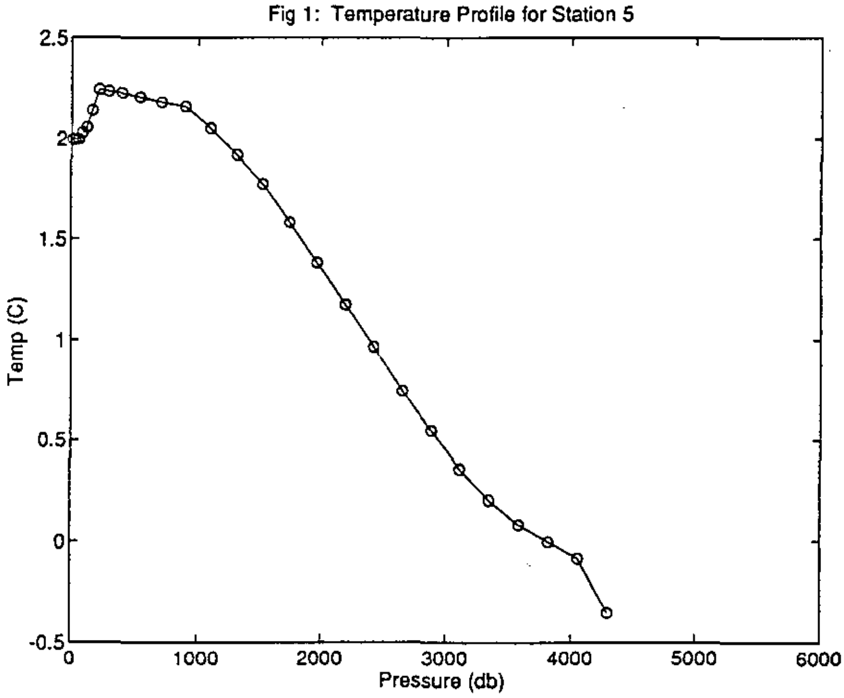
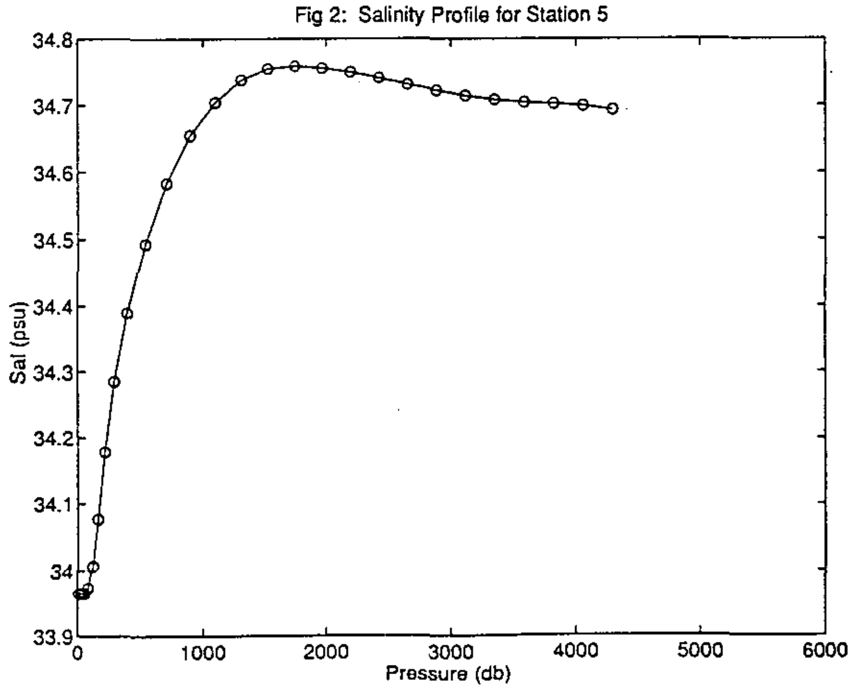


Fig 2: Salinity Profile for Station 5



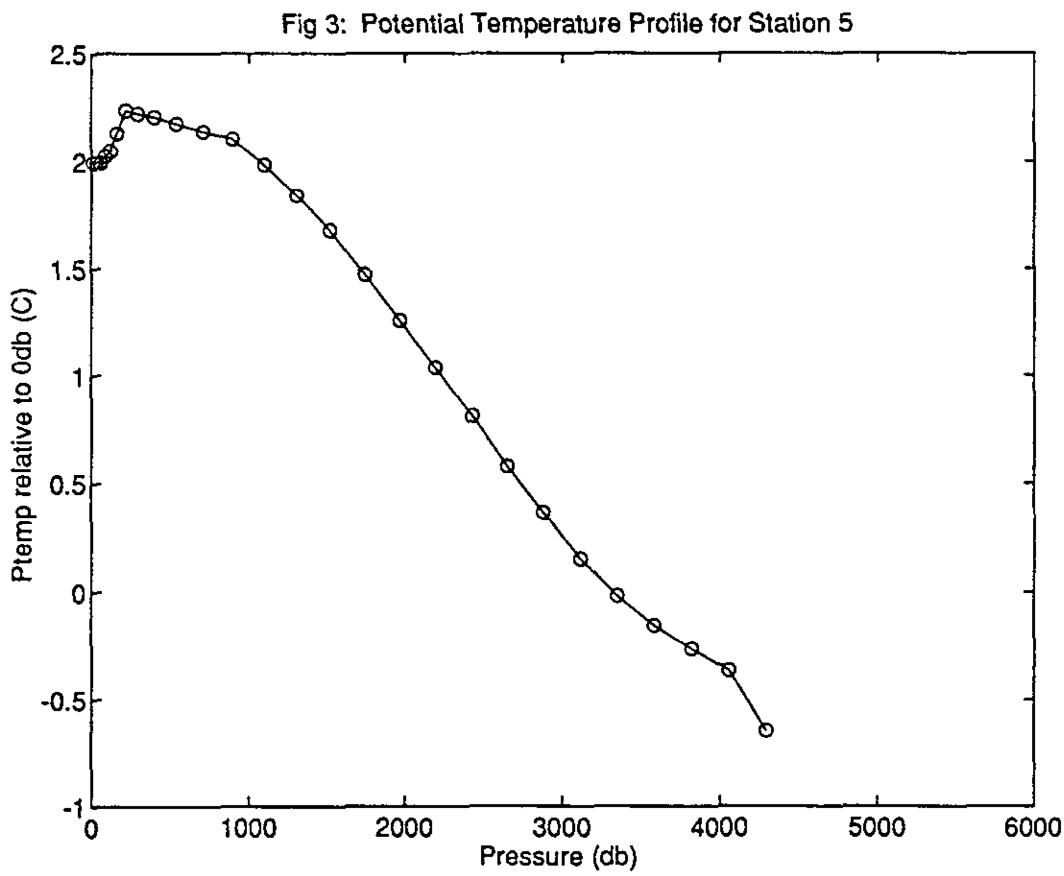
4.2 Potential Temperature Profile

The potential temperature, relative to the sea surface, for station 5 can be calculated by using the data for station 5 as follows:

```
ptmp5 = sw_ptmp(sal(:,5),temp(:,5),press,0);
```

The potential temperature profile (Figure 3) for station 5 was constructed using the following commands,

```
plot(press,ptmp5,'o')
hold on
plot(press,ptmp5,'-')
hold off
title('Potential Temperature Profile for Stations 5')
xlabel('Pressure (db) ')
ylabel('Pot. Temp. rel P=0 (C) ')
```

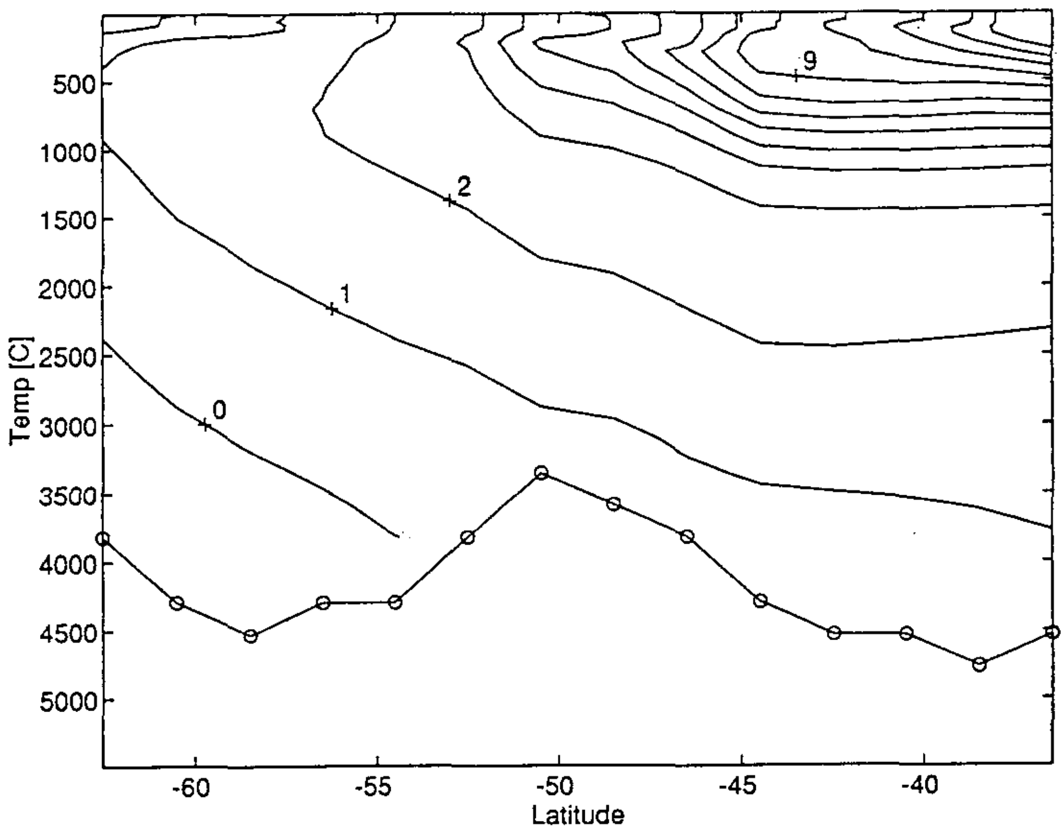


4.3 Contour Plot of Temperature, Salinity and Density

Contouring of derived properties for the entire section is also a simple matter in MATLAB. For example, contour sections for temperature (Figure 4) at intervals of 1 degree and salinity (Figure 5) at intervals of 0.1 psu with bottom topography can be generated with the following MATLAB commands:

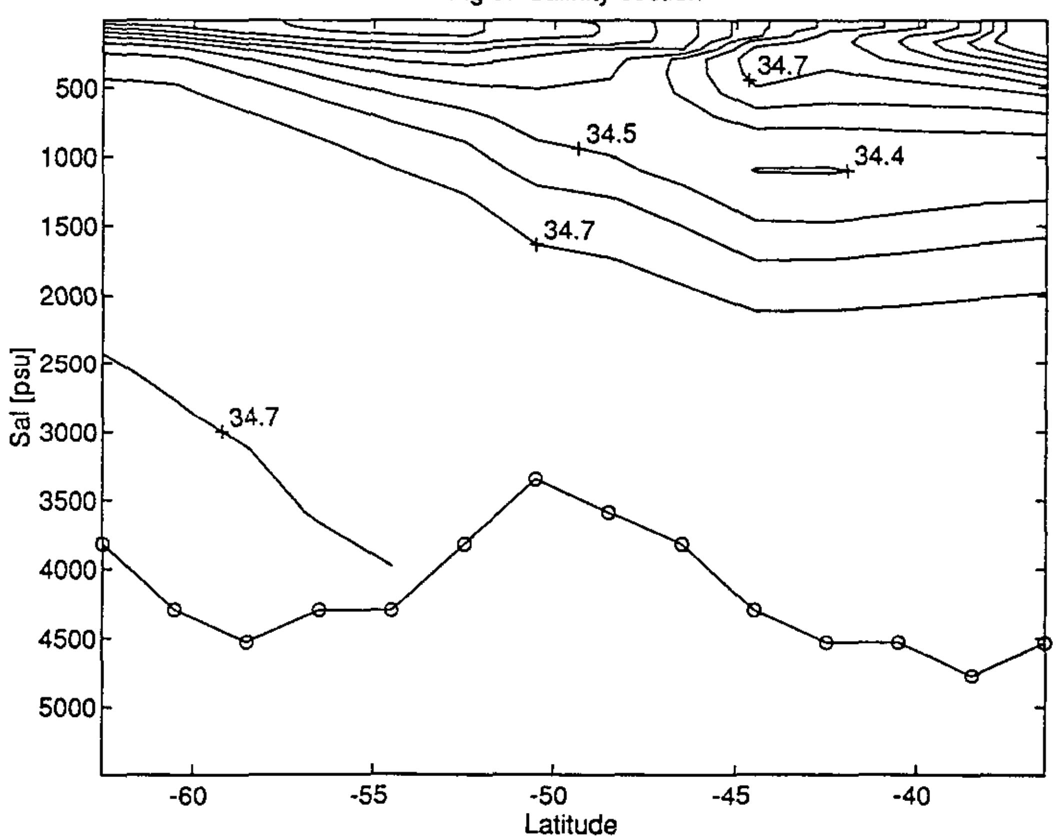
```
contlevs = [-1:1:13];
cs = contour(lat,press,temp,contlevs);
title('Temperature section')
xlabel('Latitude')
ylabel('Temp [C]')
axis('ij')
clabel(cs,'manual')
% plot bottom
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```

Fig 4: Temperature section



```
contlevs = [33.8:0.1:35.2];
cs = contour(lat,press,sal,contlevs);
title('Salinity section')
xlabel('Latitude')
ylabel('Sal [psu]')
axis('ij')
clabel(cs,'manual')
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```

Fig 5: Salinity section



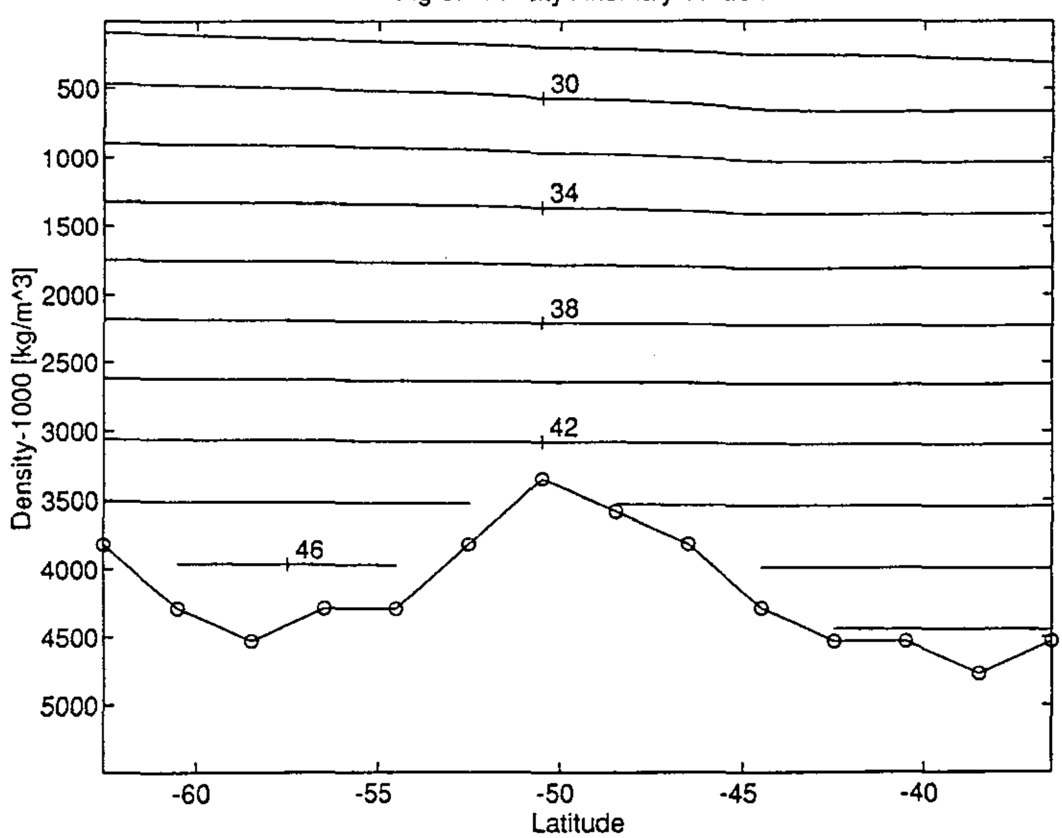
The density for the entire section can be calculated with the single command:

```
dens = sw_dens(sal,temp,press);
```

The contour section for density anomaly is readily displayed (Figure 6) with the commands:

```
contlevs = [26:2:50];
cs = contour(lat,press,dens-1000,contlevs);
title('Density Anomaly section')
xlabel('Latitude')
ylabel('Dens-1000 [kg/m^3]')
axis('ij')
clabel(cs,'manual')
hold on
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```

Fig 6: Density Anomaly section



4.4 Geostrophic Velocity

A frequent objective in oceanography is to calculate the geostrophic velocity relative to the sea surface. The routine sw_gvel requires the geopotential anomaly, so an intermediate step is needed. This can be achieved in two separate commands or you may combine the steps into one command:

```
gpan = sw_gpan(sal,temp,press);
gvel = sw_gvel(gpan,lat,lon);
% or
gvel = sw_gvel( sw_gpan(sal,temp,press) , lat,lon);
```

The geostrophic velocity relative to the 18th pressure level (2195 db) is given by:

```
nstations = length(lat);
ref_level = 18;
vel = [];
for icol  = 1:nstations-1
  vel(:,icol) = gvel(:,icol) - gvel(ref_level,icol);
end %for
```

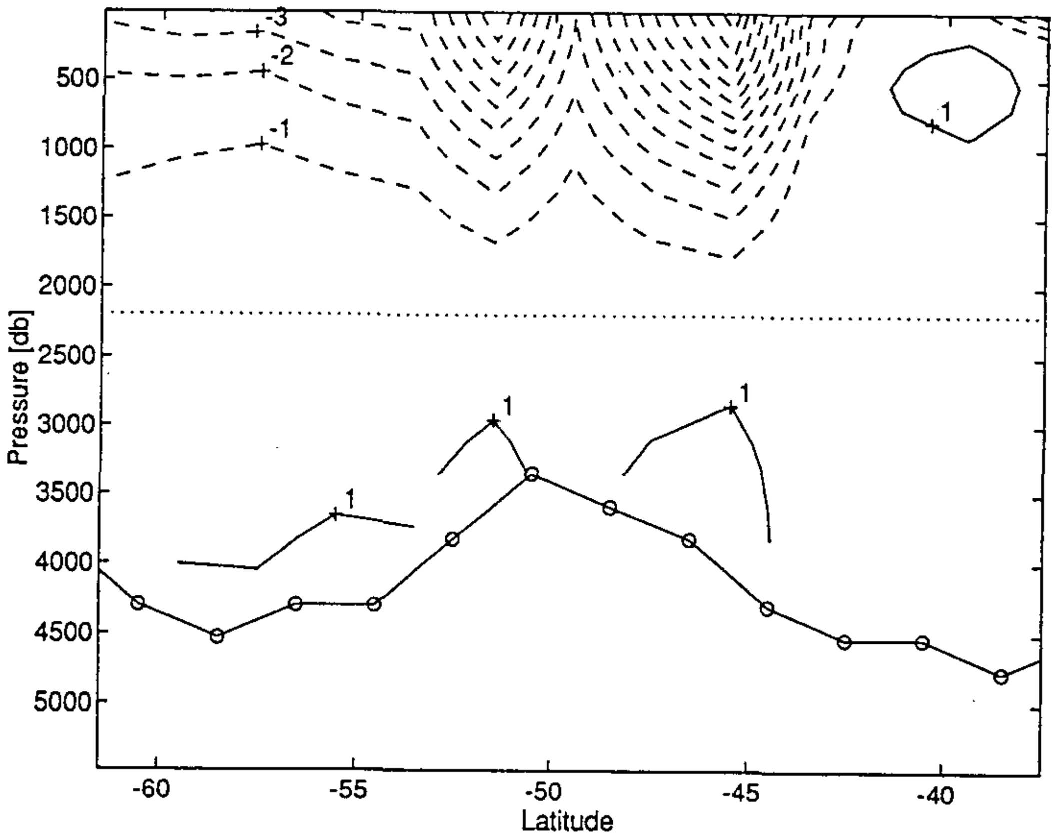
Figure 7 shows a contour plot of the geostrophic velocity relative to 2195 db. Negative values for velocity represent flow out of the page (East in this case) and are shown as broken lines, whereas positive values represent flow into the page (West in this case) and are shown as solid contour lines. The commands to generate this plot are:

```
ave_lat   = (lat(1:nstations-1)+lat(2:nstations))/2;
vel_cm    = vel*100;

contlevs = [-100:1:-1];
cs        = contour(ave_lat,press,vel_cm,contlevs,'--');
title('Geostrophic Velocity [cm/s] relative to level 18')
xlabel('Latitude')
ylabel('Pressure [db]')
axis('ij')
clabel(cs,'manual')

hold on
contlevs = [1:1:100];
cs        = contour(ave_lat,press,vel_cm,contlevs,'-');
clabel(cs,'manual')
plot(lat,press(ref_level)*ones(size(lat)),':')
plot(lat,bottom,'o')
plot(lat,bottom,'-')
hold off
```

Fig 7: Geostrophic Velocity [cm/s] relative to level 18



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Appendix A. Distribution and Installation

The SEAWATER library can be obtained by anonymous ftp to ftp.ml.csiro.au (192.67.12.100). All the files are in the directory named /pub/morgan/seawater.

The SEAWATER library can be installed in any directory but you must have the appropriate path set in MATLAB; see the MATLAB command `help path` for instructions. However, the best place to install the SEAWATER library is in the "local" directory recommended by MathWorks for user-contributed routines.

Appendix B. Example Hydrographic Dataset

A simplified example of oceanographic data is presented to aid in using the SEAWATER library for oceanographic applications. The following data represent a hydrographic section where temperature and salinity data are shown for 14 stations at 32 depths (actually pressure in the units of decibars). The stations lie on a meridional section along 117°E at intervals of 2.5 degrees. Station number 1 is located at latitude 62.5°S (near Antarctica) and station number 14 at latitude 36.5°S (near Australia).

The data equally well represent measured hydrographic data or the output from numerical models. The dataset is used throughout the tutorial in Section 4. Missing or bad data, a common problem in data analysis, have been denoted by flag values of -99.000. The data presented on the next two pages are available in the MATLAB file sw_data.m in the SEAWATER library.

Temperature (°C) section for 14 stations at 32 depths

(db)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	-0.542	0.021	0.716	1.329	1.997	2.623	4.429	5.449	6.580	8.664	9.867	10.630	12.136	15.825
33	-0.505	0.137	0.716	1.329	1.997	2.624	4.430	5.073	6.574	8.666	9.867	10.631	12.137	15.825
58	-0.527	0.153	0.801	1.329	1.997	2.624	4.430	5.034	6.574	8.666	9.867	10.631	12.137	15.825
87	-0.476	0.162	0.736	1.288	2.031	2.624	4.432	5.034	6.556	8.669	10.187	11.038	12.138	15.791
121	-0.179	0.387	0.772	1.257	2.056	2.693	4.432	5.031	6.556	8.669	10.171	11.159	12.494	15.544
163	0.287	0.842	1.036	1.363	2.139	3.024	4.817	5.097	6.546	9.373	9.952	10.990	12.556	14.767
218	0.632	1.289	1.477	1.645	2.247	3.126	5.219	5.897	6.784	9.697	9.670	10.605	12.085	13.849
292	0.835	1.561	1.752	1.821	2.237	2.950	4.905	5.596	7.543	9.611	9.670	10.313	11.281	12.792
397	0.999	1.654	1.862	1.908	2.229	2.825	4.542	5.173	7.009	9.249	9.412	9.748	10.149	11.055
537	1.128	1.683	1.917	1.987	2.207	2.633	3.996	4.530	6.114	8.498	8.839	8.919	8.884	9.158
707	1.140	1.618	1.910	2.013	2.181	2.496	3.469	3.857	5.038	7.341	7.760	7.651	7.405	7.581
896	1.023	1.497	1.832	1.994	2.159	2.388	3.015	3.259	3.986	5.594	5.959	5.910	5.749	5.739
1099	0.838	1.345	1.691	1.890	2.051	2.212	2.591	2.741	3.194	4.131	4.316	4.319	4.258	4.163
1309	0.675	1.163	1.522	1.741	1.919	2.079	2.372	2.475	2.748	3.256	3.347	3.337	3.301	3.261
1525	0.527	0.981	1.341	1.575	1.774	1.944	2.204	2.288	2.478	2.753	2.799	2.797	2.791	2.779
1746	0.301	0.730	1.094	1.353	1.584	1.774	2.043	2.128	2.320	2.512	2.532	2.540	2.539	2.538
1969	0.174	0.558	0.886	1.143	1.382	1.582	1.863	1.957	2.157	2.350	2.359	2.352	2.332	2.304
2195	0.093	0.413	0.700	0.942	1.176	1.374	1.665	1.763	1.979	2.186	2.197	2.171	2.140	2.098
2423	-0.021	0.253	0.513	0.740	0.966	1.159	1.453	1.550	1.779	2.002	2.022	1.995	1.961	1.921
2653	-0.117	0.109	0.334	0.539	0.747	0.927	1.227	1.317	1.549	1.788	1.827	1.807	1.776	1.746
2884	-0.176	-0.004	0.173	0.351	0.549	0.722	0.992	1.080	1.306	1.543	1.606	1.602	1.584	1.572
3116	-0.208	-0.103	0.036	0.181	0.354	0.515	0.778	0.853	1.093	1.300	1.367	1.385	1.392	1.404
3350	-0.281	-0.194	-0.075	0.049	0.201	0.344	0.554	0.648	0.914	1.077	1.133	1.168	1.206	1.253
3585	-0.359	-0.280	-0.168	-0.052	0.082	0.187	-99.000	0.502	0.787	0.875	0.913	0.960	1.028	1.108
3821	-0.426	-0.351	-0.250	-0.136	-0.004	0.064	-99.000	-99.000	0.672	0.708	0.733	0.775	0.858	0.973
4057	-99.000	-0.411	-0.328	-0.211	-0.085	-99.000	-99.000	-99.000	-99.000	0.587	0.594	0.627	0.709	0.843
4294	-99.000	-0.432	-0.416	-0.391	-0.354	-99.000	-99.000	-99.000	-99.000	0.535	0.496	0.525	0.593	0.718
4532	-99.000	-99.000	-0.505	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	0.435	0.472	0.517	0.570
4771	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	0.479	-99.000
5010	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
5251	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
5491	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000

Salinity (psu) section for 14 stations at 32 depths

(db)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
10	34.058	34.039	34.014	33.986	33.965	33.979	34.060	34.131	34.258	34.472	34.624	34.722	34.947	35.514
33	34.096	34.055	34.014	33.986	33.965	33.979	34.060	34.110	34.256	34.472	34.624	34.722	34.947	35.514
58	34.175	34.102	34.026	33.986	33.965	33.979	34.060	34.107	34.256	34.472	34.624	34.722	34.947	35.514
87	34.271	34.170	34.060	34.002	33.973	33.979	34.060	34.107	34.253	34.473	34.699	34.817	34.947	35.510
121	34.378	34.271	34.131	34.047	34.006	33.996	34.060	34.112	34.253	34.473	34.738	34.881	35.040	35.484
163	34.481	34.395	34.241	34.130	34.076	34.073	34.136	34.131	34.251	34.633	34.749	34.904	35.116	35.406
218	34.569	34.523	34.387	34.258	34.178	34.168	34.263	34.311	34.297	34.726	34.733	34.879	35.088	35.300
292	34.639	34.616	34.498	34.376	34.285	34.259	34.319	34.363	34.528	34.757	34.733	34.823	34.957	35.169
397	34.694	34.678	34.585	34.480	34.389	34.350	34.365	34.394	34.532	34.738	34.687	34.727	34.792	34.939
537	34.716	34.717	34.657	34.577	34.493	34.439	34.410	34.421	34.511	34.682	34.641	34.646	34.658	34.715
707	34.734	34.741	34.708	34.654	34.583	34.523	34.450	34.438	34.455	34.561	34.547	34.559	34.562	34.584
896	34.733	34.747	34.737	34.707	34.655	34.601	34.504	34.477	34.430	34.437	34.438	34.454	34.461	34.465
1099	34.730	34.747	34.750	34.738	34.704	34.658	34.560	34.528	34.459	34.397	34.395	34.414	34.429	34.436
1309	34.723	34.742	34.755	34.754	34.738	34.708	34.634	34.607	34.537	34.449	34.449	34.470	34.488	34.499
1525	34.717	34.736	34.755	34.761	34.755	34.737	34.684	34.664	34.608	34.522	34.518	34.537	34.563	34.584
1746	34.709	34.728	34.747	34.758	34.759	34.750	34.716	34.704	34.665	34.600	34.604	34.619	34.639	34.650
1969	34.706	34.721	34.737	34.750	34.756	34.755	34.738	34.733	34.710	34.669	34.673	34.682	34.692	34.699
2195	34.704	34.714	34.727	34.740	34.750	34.754	34.749	34.748	34.742	34.717	34.717	34.720	34.725	34.730
2423	34.700	34.708	34.719	34.731	34.741	34.747	34.749	34.751	34.754	34.743	34.741	34.742	34.744	34.745
2653	34.696	34.702	34.712	34.722	34.731	34.737	34.744	34.748	34.753	34.753	34.752	34.752	34.753	34.753
2884	34.693	34.698	34.705	34.714	34.722	34.727	34.737	34.740	34.748	34.754	34.755	34.756	34.757	34.757
3116	34.691	34.695	34.700	34.708	34.714	34.719	34.729	34.731	34.743	34.750	34.753	34.755	34.757	34.758
3350	34.689	34.692	34.698	34.703	34.708	34.713	34.720	34.723	34.737	34.744	34.747	34.750	34.754	34.758
3585	34.688	34.691	34.696	34.701	34.704	34.707	-99.000	34.718	34.731	34.736	34.739	34.743	34.749	34.755
3821	34.688	34.690	34.694	34.698	34.702	34.702	-99.000	-99.000	34.724	34.728	34.733	34.736	34.742	34.751
4057	-99.000	34.689	34.691	34.695	34.699	-99.000	-99.000	-99.000	-99.000	34.721	34.728	34.733	34.737	34.746
4294	-99.000	34.691	34.691	34.692	34.693	-99.000	-99.000	-99.000	-99.000	34.723	34.728	34.733	34.737	34.743
4532	-99.000	-99.000	34.693	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	34.735	34.739	34.740	34.741
4771	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	34.739	-99.000
5010	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
5251	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000
5491	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000	-99.000

Appendix C. Test Report

```
                    ********************
                    *    TEST REPORT    *
                    *                   *
                    * SEA WATER LIBRARY *
                    *                   *
                    *    Version 1.2    *
                    *                   *
                    *    13-Jan-94      *
                    ********************


*************************************
**  TESTING MODULE: sw_ptmp
**  and SUB-MODULE: sw_adtg.m
*************************************

*********************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p45)
with computed results from sw_ptmp on SUN4 computer
*********************************************************

   Sal   Temp   Press      PTMP        sw_ptmp
  (psu)   (C)    (db)       (C)          (C)
   25      0        0     0.0000     0.00000
   25     10        0    10.0000    10.00000
   25     20        0    20.0000    20.00000
   25     30        0    30.0000    30.00000
   25     40        0    40.0000    40.00000

   Sal   Temp   Press      PTMP        sw_ptmp
  (psu)   (C)    (db)       (C)          (C)
   25      0     5000    -0.3061    -0.30614
   25     10     5000     9.3531     9.35306
   25     20     5000    19.0438    19.04376
   25     30     5000    28.7512    28.75125
   25     40     5000    38.4607    38.46068


   Sal   Temp   Press      PTMP        sw_ptmp
  (psu)   (C)    (db)       (C)          (C)
   35      0        0     0.0000     0.00000
   35     10        0    10.0000    10.00000
   35     20        0    20.0000    20.00000
   35     30        0    30.0000    30.00000
   35     40        0    40.0000    40.00000

   Sal   Temp   Press      PTMP        sw_ptmp
  (psu)   (C)    (db)       (C)          (C)
   35      0     5000    -0.3856    -0.38556
   35     10     5000     9.2906     9.29064
   35     20     5000    18.9985    18.99845
   35     30     5000    28.7231    28.72314
   35     40     5000    38.4498    38.44980
```

```
*************************************************************
**   TESTING MODULE: sw_svan.m
**   and SUB-MODULE: sw_dens.m sw_dens0.m sw_smow.m sw_seck.m
**                   sw_pden.m sw_ptmp.m
*************************************************************

*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p22)
with computed results from sw_svan.m on SUN4 computer
*******************************************************

   Sal  Temp  Press       SVAN          sw_svan
  (psu)  (C)   (db)   (1e-8*m3/kg)  (1e-8*m3/kg)
    0     0      0       2749.54      2749.539
    0     0  10000       2288.61      2288.610
    0    30      0       3170.58      3170.582
    0    30  10000       3147.85      3147.853
   35     0      0          0.00         0.000
   35     0  10000          0.00         0.000
   35    30      0        607.14       607.142
   35    30  10000        916.34       916.336


*************************************************************
**   TESTING MODULE: sw_salt.m
**   and SUB-MODULE: sw_salrt.m sw_salrp.m sw_sals.m
*************************************************************

*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p9)
with computed results from sw_salt.m on SUN4 computer
*******************************************************

   Temp     Press        R              S            sw_salt
   (C)      (db)     (no units)       (psu)           (psu)
   15          0       1.00        35.000000      34.9999999
   20       2000       1.20        37.245628      37.2456277
    5       1500       0.65        27.995347      27.9953469
```

```
*************************************************************
**  TESTING MODULE: sw_cndr.m
**  and SUB-MODULE: sw_salds.m
*************************************************************

*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p14)
with computed results from sw_cndr.m on SUN4 computer
*******************************************************

   Temp     Press        S            cndr          sw_cndr
   (C)      (db)       (psu)       (no units)     (no units)
    0          0    25.000000      0.498008       0.4980083
   10          0    25.000000      0.654990       0.6549902
    0       1000    25.000000      0.506244       0.5062444
   10       1000    25.000000      0.662975       0.6629750
   10          0    40.000000      1.000073       1.0000731
   30          0    40.000000      1.529967       1.5299670

*************************************************************
**  TESTING MODULE: sw_dpth.m
*************************************************************

*******************************************************
Comparison of accepted values from Unesco 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p28)
with computed results from sw_dpth.m on SUN4 computer
*******************************************************

    Lat        Press      DPTH       sw_dpth
  (degree)     (db)      (meter)     (meter)
   0.000        500       496.65     496.653
  30.000        500       496.00     495.998
  45.000        500       495.34     495.343
  90.000        500       494.03     494.034

    Lat        Press      DPTH       sw_dpth
  (degree)     (db)      (meter)     (meter)
   0.000       5000      4915.04    4915.041
  30.000       5000      4908.56    4908.560
  45.000       5000      4902.08    4902.081
  90.000       5000      4889.13    4889.131

    Lat        Press      DPTH       sw_dpth
  (degree)     (db)      (meter)     (meter)
   0.000      10000      9725.47    9725.471
  30.000      10000      9712.65    9712.653
  45.000      10000      9699.84    9699.841
  90.000      10000      9674.23    9674.231
```

```
*************************************************************
**  TESTING MODULE: sw_fp.m
*************************************************************

*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p30)
with computed results from sw_fp.m on SUN4 computer
*******************************************************

   Sal   Press       fp          sw_fp
  (psu)   (db)       (C)          (C)
    5      0       -0.274       -0.2738
   10      0       -0.542       -0.5425
   15      0       -0.812       -0.8116
   20      0       -1.083       -1.0832
   25      0       -1.358       -1.3584
   30      0       -1.638       -1.6379
   35      0       -1.922       -1.9223
   40      0       -2.212       -2.2121

   Sal   Press       fp          sw_fp
  (psu)   (db)       (C)          (C)
    5     500      -0.650       -0.6503
   10     500      -0.919       -0.9190
   15     500      -1.188       -1.1881
   20     500      -1.460       -1.4597
   25     500      -1.735       -1.7349
   30     500      -2.014       -2.0144
   35     500      -2.299       -2.2988
   40     500      -2.589       -2.5886

*************************************************************
**  TESTING MODULE: sw_fp.m
*************************************************************

*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p37)
with computed results from sw_cp.m on SUN4 computer
*******************************************************

   Sal  Temp  Press      Cp        sw_cp
  (psu)  (C)   (db)   (J/kg.C)   (J/kg.C)
   25     0      0     4048.4     4048.44
   25    10      0     4041.8     4041.83
   25    20      0     4044.8     4044.84
   25    30      0     4049.1     4049.10
   25    40      0     4051.2     4051.22

   Sal  Temp  Press      Cp        sw_cp
  (psu)  (C)   (db)   (J/kg.C)   (J/kg.C)
   25     0    5000    3896.3     3896.26
   25    10    5000    3919.6     3919.56
   25    20    5000    3938.6     3938.60
   25    30    5000    3952.0     3952.04
   25    40    5000    3966.1     3966.11
```

```
 Sal   Temp   Press        Cp          sw_cp
(psu)   (C)    (db)    (J/kg.C)     (J/kg.C)
 35      0        0     3986.5       3986.53
 35     10        0     3986.3       3986.34
 35     20        0     3993.9       3993.85
 35     30        0     4000.7       4000.68
 35     40        0     4003.5       4003.46

 Sal   Temp   Press        Cp          sw_cp
(psu)   (C)    (db)    (J/kg.C)     (J/kg.C)
 35      0     5000     3849.3       3849.26
 35     10     5000     3874.7       3874.73
 35     20     5000     3895.0       3894.99
 35     30     5000     3909.2       3909.24
 35     40     5000     3923.9       3923.90


*************************************************************
**   TESTING MODULE: sw_svel.m
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*******************************************************
Comparison of accepted values from UNESCO 1983
 (Unesco Tech. Paper in Marine Sci. No. 44, p50)
with computed results from sw_svel.m on SUN4 computer
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 Sal   Temp   Press       SVEL         sw_svel
(psu)   (C)    (db)       (m/s)         (m/s)
 25      0        0     1435.8       1435.79
 25     10        0     1477.7       1477.68
 25     20        0     1510.3       1510.31
 25     30        0     1535.2       1535.21
 25     40        0     1553.4       1553.45

 Sal   Temp   Press       SVEL         sw_svel
(psu)   (C)    (db)       (m/s)         (m/s)
 25      0     5000     1520.4       1520.36
 25     10     5000     1561.3       1561.31
 25     20     5000     1593.6       1593.60
 25     30     5000     1619.0       1618.96
 25     40     5000     1638.0       1638.03

 Sal   Temp   Press       SVEL         sw_svel
(psu)   (C)    (db)       (m/s)         (m/s)
 35      0        0     1449.1       1449.14
 35     10        0     1489.8       1489.82
 35     20        0     1521.5       1521.46
 35     30        0     1545.6       1545.60
 35     40        0     1563.2       1563.21

 Sal   Temp   Press       SVEL         sw_svel
(psu)   (C)    (db)       (m/s)         (m/s)
 35      0     5000     1534.0       1533.97
 35     10     5000     1573.4       1573.41
 35     20     5000     1604.5       1604.48
 35     30     5000     1629.0       1628.97
 35     40     5000     1647.3       1647.30
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