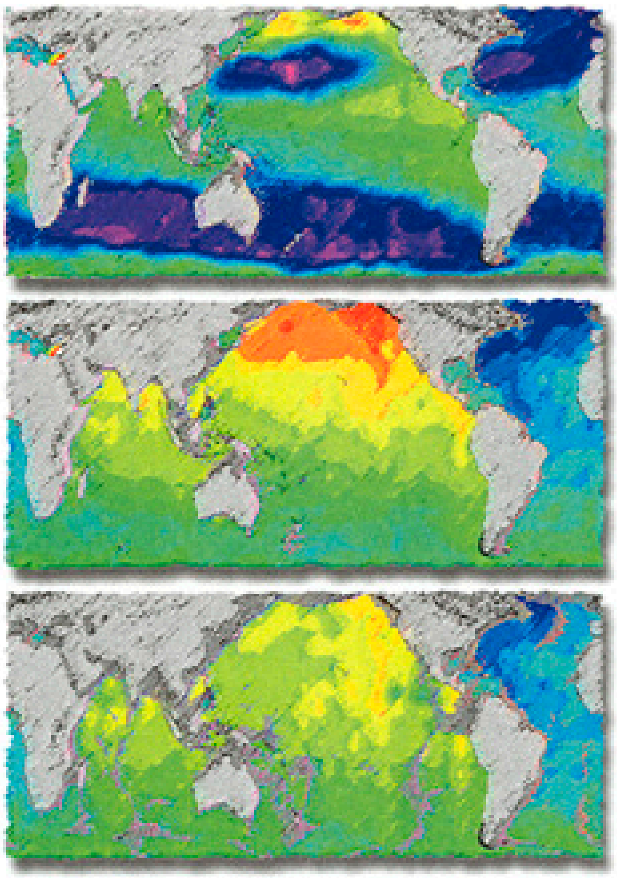
ORNL/CDIAC-127
NDP-076

# Global Distribution of Total Inorganic Carbon and Total Alkalinity Below the Deepest Winter Mixed Layer Depths



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# GLOBAL DISTRIBUTION OF TOTAL INORGANIC CARBON AND TOTAL ALKALINITY BELOW THE DEEPEST WINTER MIXED LAYER DEPTHS

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Environmental Sciences Division
Publication No. 4995

Date Published: May 2000

Prepared for the
Environmental Sciences Division
Office of Biological and Environmental Research
U.S. Department of Energy
Budget Activity Numbers KP 12 04 01 0 and KP 12 02 03 0

Prepared by the
Carbon Dioxide Information Analysis Center
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managed by
UT–BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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# ACKNOWLEDGEMENTS

The authors would like to thank all oceanographers who went to sea, performed the measurements, and were responsible for the measurements of $CO_2$ and hydrographic parameters. The authors also thank G. Monterey of Pacific Fisheries Environmental Laboratory, Pacific Grove, California, for MLD calculations at NODC. They thank the funding agencies: National Science Foundation, U.S. Department of Energy, NASA, and NOAA, for supporting the seagoing programs. This work was supported by NASA through Grant NAGW-2324.

# ABSTRACT

Goyet, C., R. J. Healy, and J. P. Ryan. 2000. Global distribution of total inorganic carbon and total alkalinity below the deepest winter mixed layer depths. ORNL/CDIAC-127, NDP-076. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee, U.S.A. 40 pp. **doi: 10.3334/CDIAC/otg.ndp076**

Modeling the global ocean-atmosphere carbon dioxide system is becoming increasingly important to greenhouse gas policy. These models require initialization with realistic three-dimensional (3-D) oceanic carbon fields. This report presents an approach to establishing these initial conditions from an extensive global database of ocean carbon dioxide ($CO_2$) system measurements and well-developed interpolation methods. These methods are limited to waters below the deepest mixed layer. The data used for these interpolations include the recent high-quality data sets from the World Ocean Circulation Experiment (WOCE), Joint Global Ocean Flux Study (JGOFS), and Ocean-Atmosphere Carbon Exchange Study (OACES) programs. Prior to analysis, all carbon data were adjusted to established reference material listed in http://www-mpl.ucsd.edu/people/adickson/CO2_QC/. The interpolation methodology employs correlation between $CO_2$ system properties and other more widely measured properties: potential temperature, salinity, and apparent oxygen utilization. The correlations are computed for each profile, and the coefficients are interpolated to the $1° \times 1° \times 32$ vertical-layer grid at a monthly temporal resolution. Finally, the gridded coefficients are applied to a global monthly climatology of ocean temperature, salinity, and oxygen to compute total $CO_2$ ($TCO_2$) and total alkalinity (TALK) for the 3-D grid.

This approach offers advantages over spin up of a single profile in defining spatial variation in $CO_2$ system properties because it reduces initialization time and provides a more accurate carbon field. The results provide an unprecedented "view" of the global distribution of TALK and $TCO_2$ in the ocean. These results as well as those from the monthly mixed layer depths can be used in diagnostic and prognostic global ocean models.

The data set of the gridded climatological fields of $TCO_2$, TALK, and mixed layer depths is available free of charge as a numeric data package from the Carbon Dioxide Information Analysis Center (CDIAC; http://cdiac.esd.ornl.gov/). The interpolated data set includes seasonal $TCO_2$ and TALK fields as well as the coefficients used to estimate these concentrations and the monthly mixed layer depths.

Keywords: Total carbon dioxide, total alkalinity, mixed layer depth, carbon fields, inorganic carbon, global ocean

# PART 1:

# OVERVIEW

# 1. INTRODUCTION

One of the main objectives of the study of the oceanic carbon cycle is to quantify the present and future role of the ocean in the absorption of anthropogenic carbon dioxide ($CO_2$). In situ data are typically used to quantify the present anthropogenic $CO_2$ concentrations in the ocean (Brewer 1978; Chen and Millero 1979; Chen 1993; Wallace 1995; Gruber et al. 1996; Gruber 1998; Peng et al. 1998; Sabine et al. 1999; Goyet et al. 1999). Global ocean models are mainly used in a prognostic mode to estimate the future penetration of anthropogenic $CO_2$ on the global scale (Sarmiento et al. 1992; Bhaskaran et al. 1995; Washington and Meehl 1996). Yet, accurate global initialization fields of the $CO_2$ properties in seawater, such as total $CO_2$ ($TCO_2$) and total alkalinity (TALK), do not exist.

In order to study the oceanic carbon cycle and to accurately describe and quantify the $TCO_2$ and TALK fields on the global scale, $TCO_2$ and TALK were measured with high accuracy throughout the water column of the major oceans. These measurements were mainly performed over the last two decades during intensive national and international field programs. Most of the data of these field programs are now freely available to the scientific community. However, these data need to be interpolated on a regular grid before they can easily be used in global ocean models.

The purpose of this work is therefore to best interpolate these data on a regular grid for use in ocean models. The interpolation is based on each measured profile from the base of the mixed layer to the bottom of the ocean. The data within the mixed layer are not considered here because they are subject to large spatial and monthly variations that are still difficult to accurately quantify. The variations of the $CO_2$ properties in the mixed layer are controlled by ocean circulation, evaporation/precipitation, dissolution of calcium carbonate, photosynthesis and oxidation of organic matter, and $CO_2$ flux across the ocean-atmosphere interface including penetration of anthropogenic $CO_2$. Many independent studies are currently designed to best quantify and parameterize each of these processes and the overall variations of the $CO_2$ properties in the mixed layer (Takahashi et al. 1997; Millero et al. 1998).

Below the mixed layer, $TCO_2$ and TALK are controlled by ocean mixing, formation/dissolution of calcium carbonate, and oxidation of organic matter (Brewer 1978). In other words, short-timescale processes do not significantly affect $TCO_2$ and TALK below the mixed layer. Thus it is possible to interpolate the data measured below the mixed layer at different times of year to acquire a reasonable understanding of the $TCO_2$ and TALK fields. In ocean areas where anthropogenic $CO_2$ is present (mainly in the upper 2000 m), it is also necessary to specify if and how data from different years are adjusted to a specific year before interpolation.

In practice, the distribution of anthropogenic $CO_2$ concentrations in the ocean is not accurately known. Estimates can differ significantly (Coatanoan et al. 2000) according to the various assumptions used. Until these differences are understood and considerably reduced, it will be very difficult to estimate pre-anthropogenic $TCO_2$ fields on the global scale. Consequently, in this paper authors interpolate the measured $TCO_2$ and TALK data without adjustment for the variations in anthropogenic $CO_2$ concentration for a given year. Because most of the data were measured within the past twenty years, such small adjustment to the different data sets (except for the North Atlantic Ocean) would mainly be within the uncertainty of the interpolated field. The results provide an estimate of these fields for the mid-1990s, when most of the accurate measurements were performed.

# 2. DATA SETS AND METHODS

In order to interpolate the measured $TCO_2$ and TALK data, the available observations were assembled (Table 1). Measurements prior to 1990 did not use the accurate standards established by Dickson (1997) for calibrating $TCO_2$. Therefore pre-1990 profiles were adjusted by comparing deep measurements within 1° of latitude and longitude, as described for the Atlantic Ocean (Goyet et al. 1997), the Pacific Ocean (Feely et al. 1998), and the Indian Ocean (Sabine et al. 1999).

All the TALK measurements were performed by potentiometry (Dyrssen 1965; Millero et al. 1998). Most of the $TCO_2$ measurements were performed by extraction/coulometry (Johnson et al. 1985, 1987, 1993, 1998) except for the cruises prior to 1990 where $TCO_2$ was measured by potentiometry. All these measurements are described in detail in the *Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water* (DOE 1994).

**Table 1. Summary of data sets used for interpolation of the $TCO_2$ and TALK fields on the global scale**

| Field program | Reference |
|---|---|
| GEOSECS[1] | Takahashi et al. 1980 |
| INDIGO[2] | Poisson et al. 1988, 1989, 1990 |
| JGOFS[3] | http://www1.whoi.edu/jgofs.html |
| OACES[4] | NOAA[8]; http://www.aoml.noaa.gov/ocd/oaces |
| TTO[5] | Data reports, TTO 1986a,b |
| WOCE[6]; SAVE[7] | CDIAC; http://cdiac.esd.ornl.gov/oceans/home.html |

[1]Geochemical Ocean Sections
[2]Indian Ocean Global Observation
[3]Joint Global Ocean Flux Study
[4]Ocean-Atmosphere Carbon Exchange Study
[5]Transient Tracers in the Ocean
[6]World Ocean Circulation Experiment
[7]South Atlantic Ventilation Experiment
[8]National Oceanographic and Atmospheric Administration

## 2.1 Determination of Monthly Mixed Layer Depth Fields

In order to define monthly mixed layer depth (MLD), a weighted average based on two sources of MLD information was created, one source based on observations and the other based on a numerical ocean model. The first was the MLD product offered by the National Ocean Data Center (NODC). Specifically, the MLD fields computed via potential density at 1° × 1° from gridded temperature/salinity (T/S) (Levitus and Boyer 1994a; Levitus et al. 1994) were used. This product is available at http://www.cdc.noaa.gov/cdc/data.nodc.woa94.html. The second source was Fleet Numerical Meteorology and Oceanography Center (FNMOC) model mixed layer output at a resolution of 2.5° × 2.5° (Clancy and Sadler 1992). Using daily FNMOC fields from March through December 1995 and January and February, 1996, monthly means were computed and then gridded to the same resolution as the NODC fields.

The T/S observations required for the NODC MLD product are highly non-uniformly distributed over the globe, and much of the ocean is completely unsampled (see Levitus and Boyer 1994a for methodology of filling the global 1° × 1° grid). As a result, the MLD fields contain unrealistic spatial distributions, horizontal gradients, and magnitudes. This problem with definition of MLD from gridded T/S is known, and a developing approach is to define MLD from individual hydrographic profiles and to grid resultant MLD estimates only where observations exist (Monterey, G., Pacific Fisheries Environmental Laboratory, Pacific Grove, Calif., personal communication.). However, such MLD fields are not currently available. Therefore, a weighting function for the NODC MLD fields was defined based on observation density. Specifically, we used the monthly average number of salinity observations at NODC levels within the upper 50 m. Based on mapped observation density, a cutoff of 75 was chosen to define where salinity was well sampled and thus where the NODC MLD fields had a sufficient observational base. Above this cutoff, the weighting for NODC MLD was 1 (~7% of the grid points). Below the cutoff, the weighting for NODC MLD was the average number of observations divided by 75. Lastly, because some NODC MLD values are extremely and unrealistically deep where few observations exist, zero weighting was assigned where NODC MLD was > 400 m. This weighting procedure retained NODC MLD estimates in relatively well-observed regions and relied on the model (FNMOC) MLD estimates for poorly observed regions (in proportion to the paucity of observations).

Following this definition of the weighted average MLD product, there still remained grid points where neither input data set provided information. Missing grid points within the latitude range 65° N to 65° S were filled with a combination of spatial and temporal averaging (±2 months and 5° of latitude/longitude). Any points not filled by this procedure were filled with the mean of all valid monthly MLD values for that grid point. Finally, a 5° × 5° median filter was applied to the monthly MLD fields to smooth the boundaries where missing data were filled in the last step.

## 2.2 Interpolation of TALK Below the Deepest Mixed Layer

Below the mixed layer, TALK can be interpolated by piecewise linear regression as a function of potential temperature (θ) and salinity (S):

$$\text{TALK} = a + b\theta + cS \qquad (1)$$

One regression was performed in each of the two layers: from the wintertime mixed layer down to 1000 m, and below 1000 m. The cutoff at 1000 m reflects the mean depth of the TALK maximum. The coefficients were calculated for each profile, interpolated to the 3-D grid using the Generic Mapping Tools (GMT) software (Wessel and Smith 1995), and applied to climatological temperature and salinity (Levitus and Boyer 1994a,b; Levitus et al. 1994) to compute TALK. Uncertainty associated with this interpolation procedure in the Indian, Pacific, and Atlantic Oceans is respectively estimated to be ±8.4 μmol/kg, ±10.2 μmol/kg, and ±4.6 μmol/kg in the upper 1000 m, and ±4.8 μmol/kg, ±9.1 μmol/kg, and ±5.9 μmol/kg at depths below 1000 m. The mean uncertainty associated with the TALK interpolation procedure in the global ocean below the mixed layer is estimated to be ±5.5 μmol/kg.

## 2.3 Interpolation of $TCO_2$ Below the Deepest Mixed Layer

As shown earlier (Goyet and Davis 1997), below the winter mixed layer, $TCO_2$ can be interpolated as a function of potential temperature ($\theta$), apparent oxygen utilization (AOU), and salinity (S):

$$TCO_2 = a + b\theta + cAOU + dS \quad (2)$$

The coefficients were calculated for each profile, interpolated to the 3-D grid using the GMT software, and applied to climatological hydrographic properties to compute $TCO_2$ at the grid points below the deepest winter mixed layer depth. Uncertainty associated with this interpolation procedure in the Indian, Pacific, and Atlantic Oceans is respectively estimated to be ±7.9 $\mu$mol/kg, ±14.5 $\mu$mol/kg, and ±8.1 $\mu$mol/kg. The mean uncertainty associated with the $TCO_2$ interpolation procedure in the global ocean below the mixed layer is estimated to be ±9.4 $\mu$mol/kg. The uncertainty is the largest in the Pacific Ocean and reflects the relatively poor data density in this large ocean.

# 3. RESULTS

The results of this work are monthly global fields of $TCO_2$ and TALK, the coefficients used to compute these $CO_2$ system properties, and the maximum mixed layer depths used to define the shallowest depth for these computations. Figure 1 shows the geographical distribution of the maximum depth of the mixed layer. The deepest mixed layers are observed in the northern Atlantic Ocean. The Southern Ocean south of 50° S is a large area with deep mixed layers as a result of the strong atmospheric forcing. The shallowest (< 20 m) mixed layers are observed at low latitudes.

Figures 2 and 3 illustrate the annual mean concentrations of $TCO_2$ and TALK, respectively, at 500 m, 1500 m, and 3500 m between 60° N and 60° S. These maps clearly show the differences between the three major oceans. In the Pacific Ocean, $TCO_2$ concentrations are generally higher on the eastern side than on the western side (Fig. 2). At 500 m, $TCO_2$ concentrations have the signature of the upper layers and reflect the circulation patterns. The equatorial upwelling is particularly evident with $TCO_2$ concentrations higher on the eastern side than the western side.

At 1500 m, the highest concentrations are observed in the Pacific Ocean north of 35° N, while the lowest concentrations are observed in the Atlantic Ocean north of 35° N. At 3500 m, $TCO_2$ concentrations in the Indian Ocean are comparable to those in the Pacific Ocean at similar latitudes. The lowest $TCO_2$ concentrations are observed in the northwestern Atlantic Ocean. At 3500 m, $TCO_2$ concentrations typically differ by 200 $\mu$mol/kg or more between the different ocean basins of the Northern Hemisphere. In contrast, in the Southern Hemisphere south of 40° S, the variation of $TCO_2$ concentration between oceans is typically less than 50 $\mu$mol/kg.

At 500 m, TALK is lowest in the Pacific Ocean. However, at 1500 and 3500 m, TALK is lowest in the Atlantic Ocean. In contrast to $TCO_2$, the highest TALK concentrations are in the northern Indian Ocean.

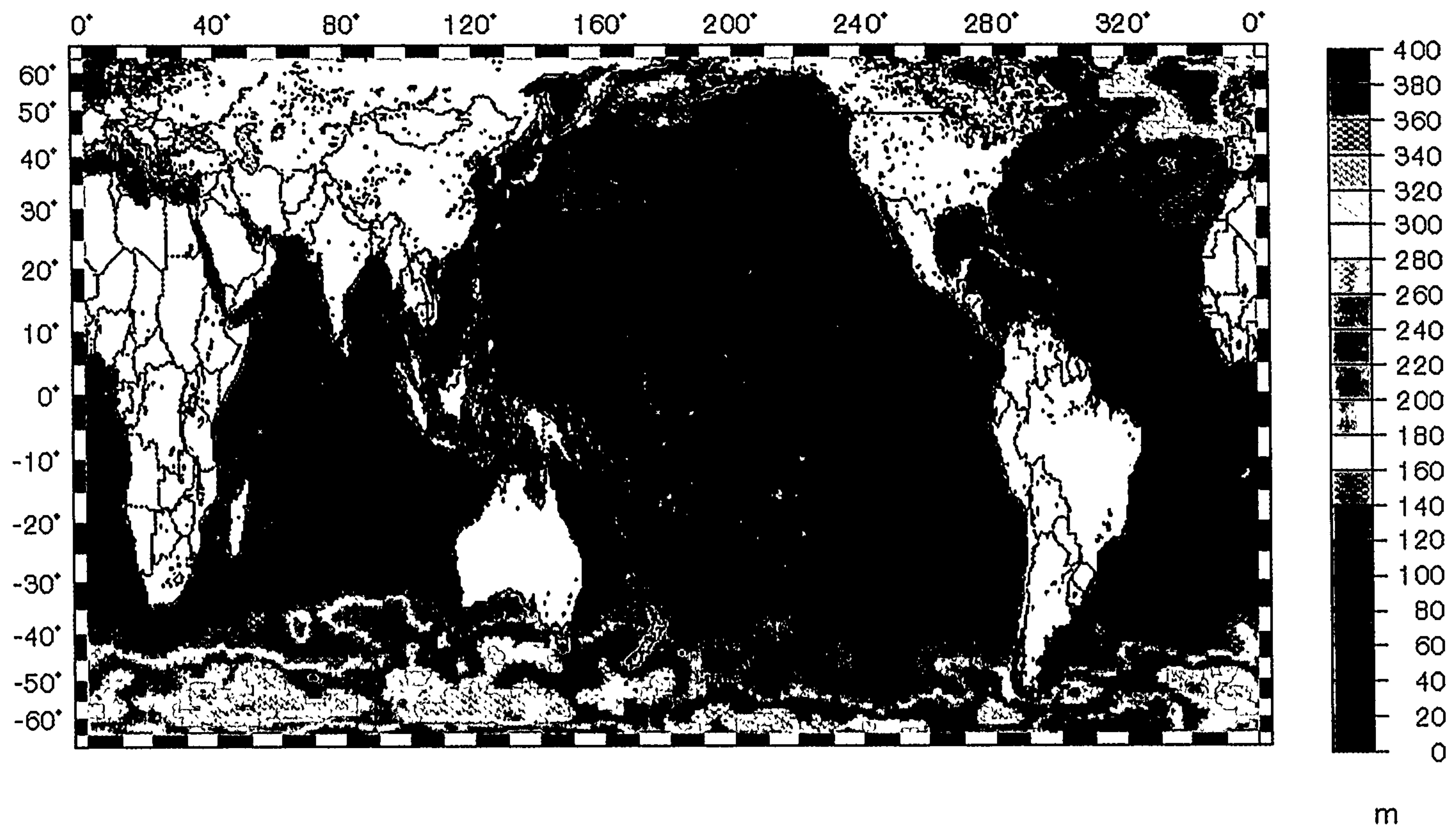


Fig. 1. Spatial distribution of the maximum depth (m) of the mixed layer.

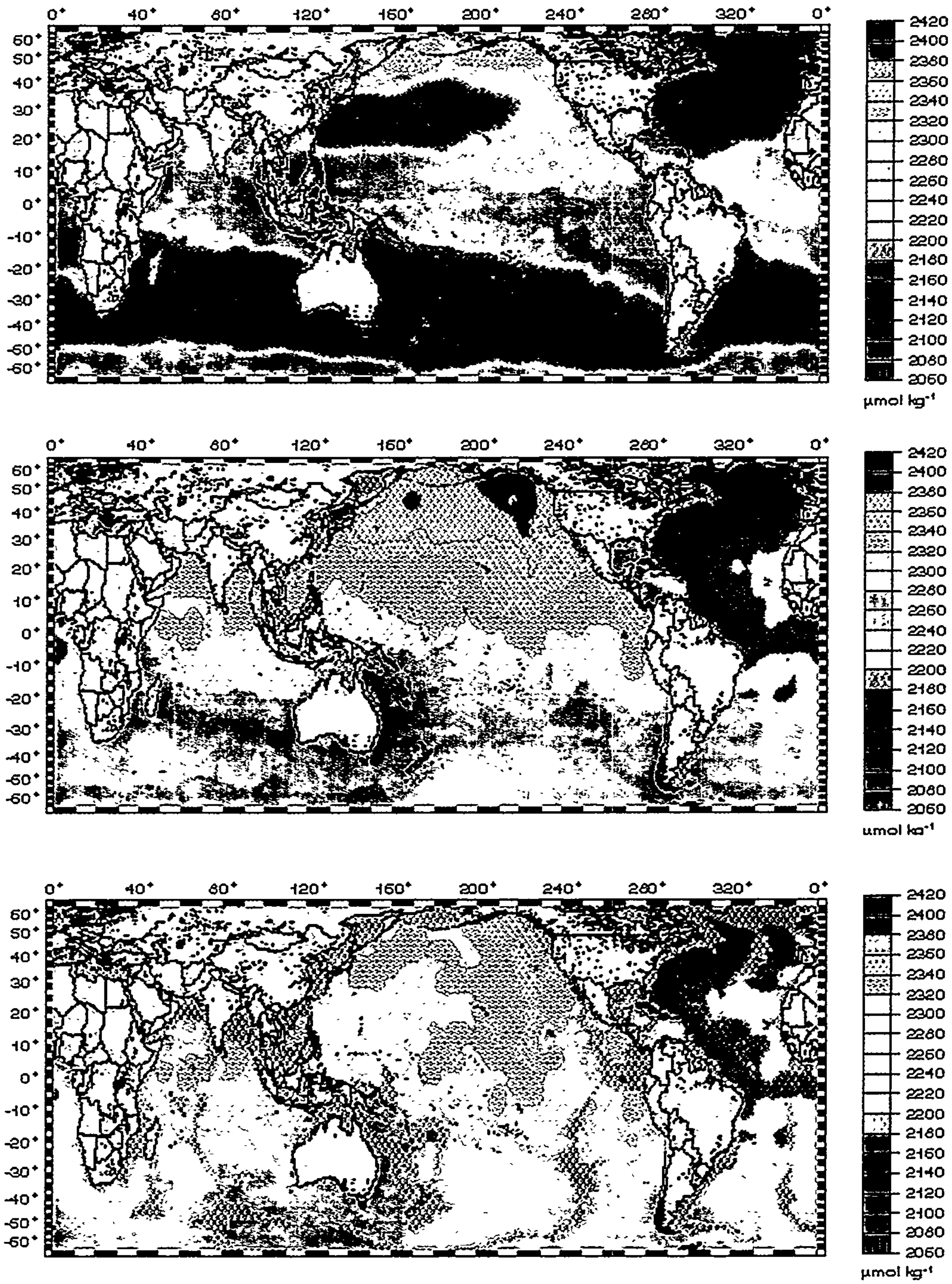


**Fig. 2. Spatial distribution of the annual mean $TCO_2$ ($\mu$mol/kg) at 500 m (top), 1500 m (middle), and 3500 m (bottom).**

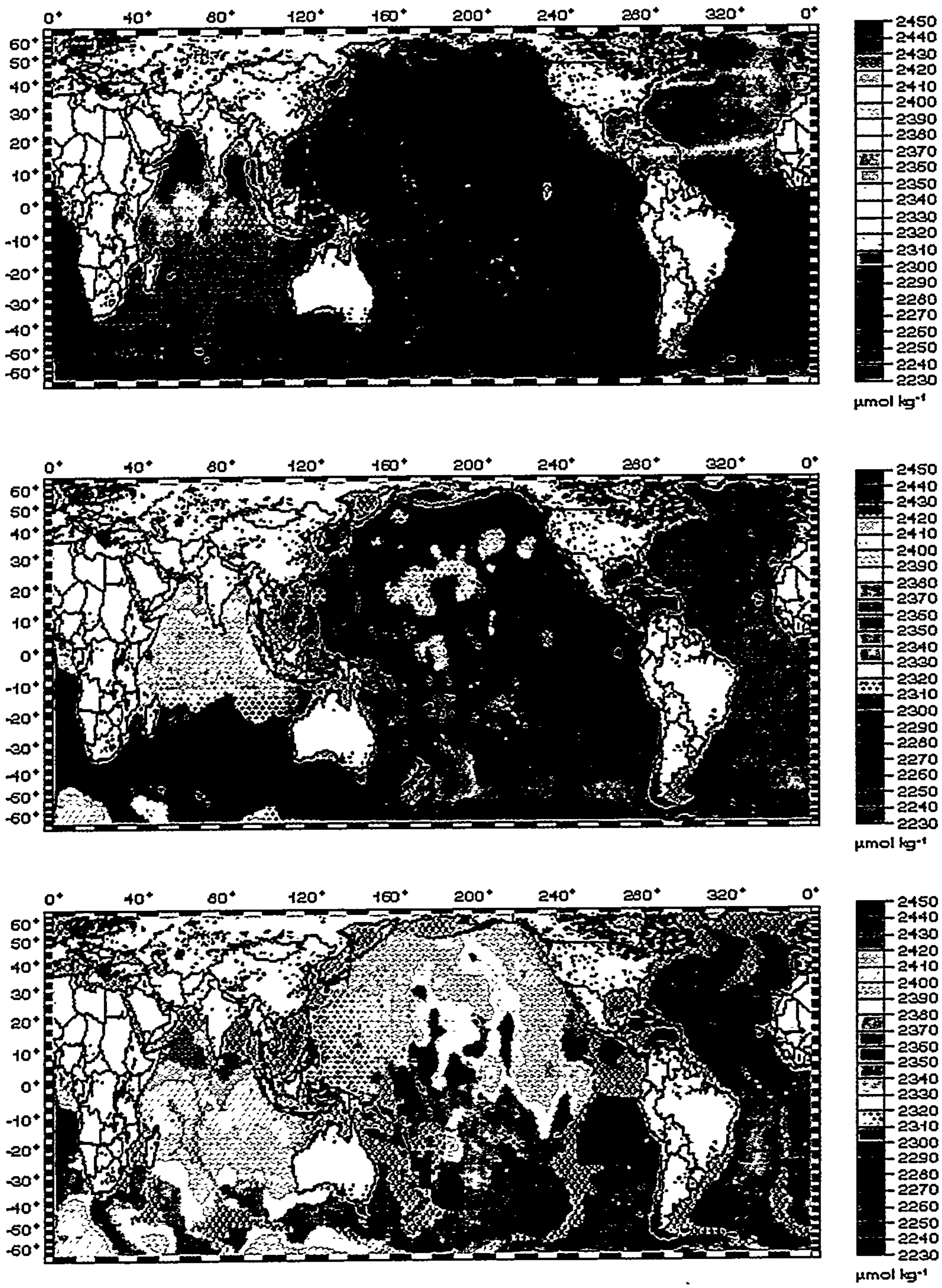


**Fig. 3. Spatial distribution of the annual mean TALK ($\mu$mol/kg) at 500 m (top), 1500 m (middle), and 3500 m (bottom).**

Overall, the distribution of $TCO_2$ and TALK in seawater reflects the circulation of the different water masses. Briefly, in the North Atlantic Ocean the waters are young and the concentration of $TCO_2$ is relatively low, whereas the concentration of TALK is relatively high. However, because it is a location of deep water formation, the $TCO_2$ gradient from the surface to the bottom is relatively small, and anthropogenic $CO_2$ penetrates to the bottom (Chen 1993). From the North Atlantic Ocean the water flows to the South Atlantic Ocean and to the Southern Ocean before going into the North Indian and North Pacific Oceans, where $TCO_2$ concentrations are the highest.

## 4. SUMMARY

Understanding the complex, interacting processes that determine global ocean uptake of atmospheric $CO_2$ requires accurate definition of initial conditions and accurate representation of the processes forcing variation. An approach to defining global, monthly 3-D fields of $TCO_2$ and TALK below the deepest mixed layer was presented in this report. These fields are now available to the scientific community through CDIAC. The accuracy of these interpolated fields is the best available today given the in situ data fields. They accurately reflect the main characteristics of global water mass circulation. This approach offers advantages over spin up of a single profile in defining spatial variation in $CO_2$ system properties because it provides a more accurate carbon field and reduces initialization time. As additional data become available, it will be possible to increase the accuracy of mixed layer depths, $TCO_2$, and TALK fields.

## 5. HOW TO OBTAIN THE DATA AND DOCUMENTATION

This database (NDP-076) is available free of charge from CDIAC. The data are available from CDIAC's anonymous file transfer protocol (FTP) area via the Internet. Please note: Your computer needs to have FTP software loaded on it (this is built in to most newer operating systems). Use the following commands to obtain the database.

```
>ftp cdiac.esd.ornl.gov  or  >ftp 128.219.24.36
Login: "anonymous" or "ftp"
Password: your e-mail address
ftp> cd pub/ndp076/
ftp> dir
ftp> mget (files)
ftp> quit
```

The complete documentation and data can also be obtained from the CDIAC oceanographic Web site (http://cdiac.esd.ornl.gov/oceans/doc.html), through CDIAC's online ordering system (http://cdiac.esd.ornl.gov/pns/how_order.html), or by contacting CDIAC.

Contact information:

Carbon Dioxide Information Analysis Center
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Oak Ridge, Tennessee 37831-6335
U.S.A.

Telephone: 865-574-3645
Telefax: 865-574-2232

E-mail: cdiac@ornl.gov

Internet: http://cdiac.esd.ornl.gov/

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# PART 2:

# CONTENT AND FORMAT OF DATA FILES

# 7. FILE DESCRIPTIONS

This section describes the content and format of each of the 19 files that comprise this numeric data package (NDP) (see Table 2). Because CDIAC distributes the data set in several ways (e.g., via anonymous FTP and on floppy diskette), each of the 19 files is referenced by both an ASCII file name, which is given in lowercase, bold-faced type (e.g., **ndp076.txt**) and a file number. The remainder of this section describes (or lists, where appropriate) the contents of each file.

**Table 2. Content, size, and format of data files**

| File number, name, and description | Logical records | File size in bytes |
|---|---|---|
| 1. **ndp076.txt**: a detailed description of the data set, methods of calculations of carbon fields, the five FORTRAN 77 data-retrieval routines, and the thirteen oceanographic data files | 1,904 | 58,117 |
| 2. **coef_talk.for:** a FORTRAN 77 data-retrieval routine to read and print **coef_talk.dat** (File 7) | 45 | 1,430 |
| 3. **coef_tco2.for:** a FORTRAN 77 data-retrieval routine to read and print **coef_tco2.dat** (File 8) | 39 | 1,160 |
| 4. **mld1x1.for**: a FORTRAN 77 data-retrieval routine to read and print **mld1x1.dat** (File 9) | 47 | 1,631 |
| 5. **talkdat.for**: a FORTRAN 77 data-retrieval routine to read and print **talk_*.dat** (Files 10–14) | 44 | 1,456 |
| 6. **tco2dat.for**: a FORTRAN 77 data-retrieval routine to read and print **tco2_*.dat** (Files 15–19) | 41 | 1,285 |
| 7. **coef_talk.dat**: a listing of the *a*, *b*, and *c* coefficients used to calculate TALK fields | 48,387 | 4,403,002 |
| 8. **coef_tco2.dat**: a listing of the *a*, *b*, *c*, and *d* coefficients used to calculate $TCO_2$ fields | 48,387 | 3,096,806 |

**Table 2. (continued)**

| File number, name, and description | Logical records | File size in bytes |
|---|---|---|
| 9. **mld1x1.dat:** mixed layer depths (1°×1° grid) calculated for each month of the year | 34,144 | 4,574,721 |
| 10–14. **talk_*.dat:** interpolated TALK fields calculated annually and for each quarter | 4,973,480 | 447,612,905 |
| 15–19. **tco2_*.dat:** interpolated $TCO_2$ fields calculated annually and for each quarter | 4,980,110 | 323,714,083 |
| **Total** | 10,085,818 | 783,466,596 |

## 7.1 ndp076.txt (File 1)

This file contains a detailed description of the data set, methods of calculations, the five FORTRAN 77 data-retrieval routines, and the thirteen oceanographic data files. It exists primarily for the benefit of individuals who acquire this database as machine-readable data files from CDIAC.

## 7.2 coef_talk.for (File 2)

This file contains a FORTRAN 77 data-retrieval routine to read and print **coef_talk.dat** (File 7). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **coef_talk.dat** in Sect. 7.7.

```
c*********************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file
c* named "coef_talk.dat" (File 7)
c*********************************************************************

c*Defines variables*

      REAL lon, lat, coef1, coef2, coef3, coef4, coef5
      REAL coef6
      OPEN (unit=1, file='coef_talk.dat')
      OPEN (unit=2, file='coef_talk.txt')
      write (2, 5)
```

```
c*Writes out column labels*

 5      format (2X,'LONG',4X,'LAT',2X,'A_COEFF_OFST',1X,
     1 'A_COEFF_OFST',2X,'B_COEFF_TMP',2X,'B_COEFF_TMP',
     2 1X,'C_COEFF_SAL',1X,'C_COEFF_SAL',/,3X,'DEG',4X,
     3 'DEG',5X,'MLD-1000M',7X,'>1000M',4X,'MLD-1000M',
     4 7X,'>1000M',3X,'MLD-1000M',6X,'>1000M')

c*Sets up a loop to read and format all the data in the file*

        read (1, 6)
 6      format (///////////)

 7      CONTINUE
        read (1, 10, end=999) lon, lat, coef1, coef2, coef3, coef4,
     1 coef5, coef6

 10     format (F6.1, 1X, F6.1, 2X, F12.4, 1X, F12.4, 1X, F12.5,
     1 1X, F12.5, 1X, F11.4, 1X, F11.4)

        write (2, 20) lon, lat, coef1, coef2, coef3, coef4,
     1 coef5, coef6

 20     format (F6.1, 1X, F6.1, 2X, F12.4, 1X, F12.4, 1X, F12.5,
     1 1X, F12.5, 1X, F11.4, 1X, F11.4)

        GOTO 7
 999    close(unit=1)
        close(unit=2)
        stop
        end
```

## 7.3 coef_tco2.for (File 3)

This file contains a FORTRAN 77 data-retrieval routine to read and print **coef_tco2.dat** (File 8). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **coef_tco2.dat** in Sect. 7.8.

```
c*****************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file
c* named "coef_tco2.dat" (File 8)
c*****************************************************************

c*Defines variables*

        REAL lon, lat, coefa, coefb, coefc, coefd
        OPEN (unit=1, file='coef_tco2.dat')
        OPEN (unit=2, file='coef_tco2.txt')
        write (2, 5)

c*Writes out column labels*

 5      format (2X,'LONG', 4X,'LAT',6X,'A_COEFF',5X,'B_COEFF',
     1 6X,'C_COEFF',5X,'D_COEFF',/,3X,'DEG',4X,'DEG')

c*Sets up a loop to read and format all the data in the file*
```

```
      read (1, 6)
 6    format (///////////)

 7    CONTINUE
      read (1, 10, end=999) lon, lat, coefa, coefb, coefc, coefd

 10   format (F6.1, 1X, F6.1, 2X, F11.4, 1X, F11.5, 1X, F12.6,
     1 1X, F11.5)

      write (2, 20) lon, lat, coefa, coefb, coefc, coefd

 20   format (F6.1, 1X, F6.1, 2X, F11.4, 1X, F11.5, 1X, F12.6,
     1 1X, F11.5)

      GOTO 7
 999  close(unit=1)
      close(unit=2)
      stop
      end
```

## 7.4 mld1x1.for (File 4)

This file contains a FORTRAN 77 data-retrieval routine to read and print **mld1x1.dat** (File 9). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **mld1x1.dat** in Sect. 7.9.

```
c*********************************************************************
c* FORTRAN 77 data retrieval routine to read and print the file
c* named "mld1x1.dat" (File 9)
c*********************************************************************

c*Defines variables*

      REAL lon, lat, max, jan, feb, mar, apr, may, jun, jul
      REAL aug, sep, oct, nov, dec
      OPEN (unit=1, file='mld1x1.dat')
      OPEN (unit=2, file='mld1x1.txt')
      write (2, 5)

c*Writes out column labels*

 5    format (4X,'LONG',5X,'LAT',2X,'MLD_MAX',2X,'MLD_JAN',
     1 2X,'MLD_FEB',2X,'MLD_MAR',2X,'MLD_APR',2X,'MLD_MAY',
     2 2X,'MLD_JUN',2X,'MLD_JUL',2X,'MLD_AUG',2X,'MLD_SEP',
     3 2X,'MLD_OCT',2X,'MLD_NOV',2X,'MLD_DEC',/,
     4 5X,'DEG',5X,'DEG',8X,13('M',8X))

c*Sets up a loop to read and format all the data in the file*

      read (1, 6)
 6    format (///////////)

 7    CONTINUE
      read (1, 10, end=999) lon, lat, max, jan, feb, mar,
     1 apr, may, jun, jul, aug, sep, oct, nov, dec

 10   format (F8.2, 1X, F7.2, 1X, F8.4, 1X, F8.4, 1X, F8.4,
     1 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X,
```

```
     2 F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4)

       write (2, 20) lon, lat, max, jan, feb, mar,
     1 apr, may, jun, jul, aug, sep, oct, nov, dec

 20    format (F8.2, 1X, F7.2, 1X, F8.4, 1X, F8.4, 1X, F8.4,
     1 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X,
     2 F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4)

       GOTO 7
 999   close(unit=1)
       close(unit=2)
       stop
       end
```

## 7.5 talkdat.for (File 5)

This file contains a FORTRAN 77 data-retrieval routine to read and print **talk_*.dat** (Files 10–14). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **talk_*.dat** in Sect. 7.10.

```
c*********************************************************************
c* FORTRAN 77 data retrieval routine to read and print the files
c* named "talk_*.dat" (Files 10-14)
c*********************************************************************

c*Defines variables*

       REAL lon, lat, dep, mld, talk, tmp, sal, coefa, coefb
       REAL coefc
       OPEN (unit=1, file='talk_*.dat')
       OPEN (unit=2, file='talk_*.txt')
       write (2, 5)

c*Writes out column labels*

 5     format (3X,'LONG',4X,'LAT',3X,'DEPTH',5X,'MLD',6X,
     1'TALK', 4X,'TEMP',2X,'SALNTY',4X,'A_COEFF',4X,
     2 'B_COEFF',4X,'C_COEFF',/,4X,'DEG',4X,'DEG',7X,'M',
     3 7X,'M',3X,'UMOL/KG',5X,'DEG',2X,'PSS-78',5X,'OFFSET',
     4 7X,'TEMP',5X,'SALNTY',/)
c*Sets up a loop to read and format all the data in the file*

       read (1, 6)
 6     format (///////////)

 7     CONTINUE
       read (1, 10, end=999) lon, lat, dep, mld, talk, tmp,
     1 sal, coefa, coefb, coefc

 10    format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F10.3, 1X, F10.3, 1X, F10.3)

       write (2, 20) lon, lat, dep, mld, talk, tmp,
     1 sal, coefa, coefb, coefc

 20    format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F10.3, 1X, F10.3, 1X, F10.3)
```

```
      GOTO 7
999   close(unit=1)
      close(unit=2)
      stop
      end
```

## 7.6 tco2dat.for (File 6)

This file contains a FORTRAN 77 data-retrieval routine to read and print **tco2_*.dat** (Files 15–19). The following is a listing of this program. For additional information regarding variable definitions, variable lengths, variable types, units, and codes, please see the description for **tco2_*.dat** in Sect. 7.11.

```
cc*******************************************************************
c* FORTRAN 77 data retrieval routine to read and print the files
c* named "tco2_*.dat" (Files 15-19)
c********************************************************************

c*Defines variables*

      REAL lon, lat, dep, mld, trco2, tmp, aou, sal
      OPEN (unit=1, file='tco2_*.dat')
      OPEN (unit=2, file='tco2_*.txt')
      write (2, 5)

c*Writes out column labels*

 5    format (3X,'LONG',4X,'LAT',3X,'DEPTH',5X,'MLD',6X,'TCO2',
     1 4X,'TEMP',5X,'AOU',2X,'SALNTY',/,4X,'DEG',4X,'DEG',7X,'M',
     2 7X,'M',3X,'UMOL/KG',5X,'DEG',1X,'UMOL/KG',2X,'PSS-78',/)

c*Sets up a loop to read and format all the data in the file*

      read (1, 6)
 6    format (///////////)

 7    CONTINUE
      read (1, 10, end=999) lon, lat, dep, mld, trco2, tmp,
     1 aou, sal

 10   format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F7.3)

      write (2, 20) lon, lat, dep, mld, trco2, tmp, aou, sal

 20   format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F7.3)

      GOTO 7
999   close(unit=1)
      close(unit=2)
      stop
      end
```

## 7.7 coef_talk.dat (File 7)

This file provides the coefficients *a*, *b*, and *c* used to calculate TALK from the potential temperature (T) and salinity (S). Each line of the file contains a longitude, latitude, offset coefficient *a* (between depths MLD and 1000 m), offset coefficient *a* (below 1000 m), T coefficient *b* (between depths MLD and 1000 m), T coefficient *b* (below 1000 m), S coefficient *c* (between depths MLD and 1000 m), and S coefficient *c* (below 1000 m). The file is sorted by longitude and latitude and can be read by using the following FORTRAN 77 code (contained in **coef_talk.for**, File 2):

```
      REAL lon, lat, coef1, coef2, coef3, coef4, coef5
      REAL coef6

      read (1, 10, end=999) lon, lat, coef1, coef2, coef3, coef4,
     1 coef5, coef6

 10   format (F6.1, 1X, F6.1, 2X, F12.4, 1X, F12.4, 1X, F12.5,
     1 1X, F12.5, 1X, F11.4, 1X, F11.4)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **lon** | Numeric | 6 | 1 | 6 |
| **lat** | Numeric | 6 | 8 | 13 |
| **coef1** | Numeric | 12 | 16 | 27 |
| **coef2** | Numeric | 12 | 29 | 40 |
| **coef3** | Numeric | 12 | 42 | 53 |
| **coef4** | Numeric | 12 | 55 | 66 |
| **coef5** | Numeric | 11 | 68 | 78 |
| **coef6** | Numeric | 11 | 80 | 90 |

The variables are defined as follows:

**lon** is the longitude for which coefficients were calculated;

**lat** is the latitude for which coefficients were calculated;

**coef1** is the offset coefficient *a* (for depths between MLD and 1000 m);

**coef2** is the offset coefficient *a* (for depths below 1000 m);

**coef3** is the T coefficient *b* (for depths between MLD and 1000 m);

**coef4** is the T coefficient *b* (for depths below 1000 m);

**coef5** is the S coefficient *c* (for depths between MLD and 1000 m); and

**coef6** is the S coefficient *c* (for depths below 1000 m).

## 7.8 coef_tco2.dat (File 8)

This file provides the coefficients *a*, *b*, *c*, and *d* used to calculate $TCO_2$ from the T, apparent oxygen utilization (AOU), and S. Each line of the file contains a longitude, latitude, offset coefficient *a* (below MLD), T coefficient *b* (below MLD), AOU coefficient *c* (below 1000 m), and S coefficient *d* (below MLD). The file is sorted by longitude and latitude and can be read by using the following FORTRAN 77 code (contained in **coef_tco2.for**, File 3):

```
      REAL lon, lat, coefa, coefb, coefc, coefd

      read (1, 10, end=999) lon, lat, coefa, coefb, coefc, coefd

 10   format (F6.1, 1X, F6.1, 2X, F11.4, 1X, F11.5, 1X, F12.6,
     1 1X, F11.5)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **lon** | Numeric | 6 | 1 | 6 |
| **lat** | Numeric | 6 | 8 | 13 |
| **coefa** | Numeric | 11 | 16 | 26 |
| **coefb** | Numeric | 11 | 28 | 38 |
| **coefc** | Numeric | 12 | 40 | 51 |
| **coefd** | Numeric | 11 | 53 | 63 |

The variables are defined as follows:

**lon** is the longitude for which coefficients were calculated;

**lat** is the latitude for which coefficients were calculated;

**coefa** is the offset coefficient *a* (for depths below MLD);

**coefb** is the T coefficient *b* (for depths below MLD);

**coefc** is the AOU coefficient *c* (for depths below MLD; and

**coefd** is the S coefficient *d* (for depths below MLD).

## 7.9 mld1x1.dat (File 9)

This file provides a mixed layer depths (1° × 1° grid) calculated for each month of the year. The file is sorted by longitude and latitude and can be read by using the following FORTRAN 77 code (contained in **mld1x1.for**, File 4):

```
      REAL lon, lat, max, jan, feb, mar, apr, may, jun, jul
      REAL aug, sep, oct, nov, dec

      read (1, 10, end=999) lon, lat, max, jan, feb, mar,
     1 apr, may, jun, jul, aug, sep, oct, nov, dec

 10   format (F8.2, 1X, F7.2, 1X, F8.4, 1X, F8.4, 1X, F8.4,
     1 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X,
     2 F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4, 1X, F8.4)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **lon** | Numeric | 8 | 1 | 8 |
| **lat** | Numeric | 7 | 10 | 16 |
| **max** | Numeric | 8 | 18 | 25 |
| **jan** | Numeric | 8 | 27 | 34 |
| **feb** | Numeric | 8 | 36 | 43 |
| **mar** | Numeric | 8 | 45 | 52 |
| **apr** | Numeric | 8 | 54 | 61 |
| **may** | Numeric | 8 | 63 | 70 |
| **jun** | Numeric | 8 | 72 | 79 |
| **jul** | Numeric | 8 | 81 | 88 |
| **aug** | Numeric | 8 | 90 | 97 |
| **sep** | Numeric | 8 | 99 | 106 |
| **oct** | Numeric | 8 | 108 | 115 |
| **nov** | Numeric | 8 | 117 | 124 |
| **dec** | Numeric | 8 | 126 | 133 |

The variables are defined as follows:

**lon** is the longitude for which MLDs were calculated;

**lat** is the latitude for which MLDs were calculated;

**max** is the year maximum MLD;

**jan–dec** is the calculated MLD for each month of the year.

## 7.10 talk_*.dat (Files 10–14)

These files provide the interpolated TALK fields calculated annually and for each quarter (talk_ann.dat, talk_djf.dat, talk_mam.dat, talk_jja.dat, and talk_son.dat). The files are sorted by longitude and latitude and can be read by using the following FORTRAN 77 code (contained in **talkdat.for**, File 5):

```
      REAL lon, lat, dep, mld, talk, tmp, sal, coefa, coefb
      REAL coefc

      read (1, 10, end=999) lon, lat, dep, mld, talk, tmp,
     1 sal, coefa, coefb, coefc

 10   format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F10.3, 1X, F10.3, 1X, F10.3)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **lon** | Numeric | 7 | 1 | 7 |
| **lat** | Numeric | 6 | 9 | 14 |
| **dep** | Numeric | 7 | 16 | 22 |
| **mld** | Numeric | 7 | 24 | 30 |
| **talk** | Numeric | 9 | 32 | 40 |
| **tmp** | Numeric | 7 | 42 | 48 |
| **sal** | Numeric | 7 | 50 | 56 |
| **coefa** | Numeric | 10 | 58 | 67 |
| **coefb** | Numeric | 10 | 69 | 78 |
| **coefc** | Numeric | 10 | 80 | 89 |

The variables are defined as follows:

**lon** is the longitude for which TALK was calculated;

**lat** is the latitude for which TALK was calculated;

**dep** is the depth for which TALK was calculated (m);

**mld** is the maximum layer depth (m);

**talk** is the total alkalinity ($\mu$mol/kg);

**tmp** is the temperature (°C);

**sal** is the salinity;

**coefa** is the *a* coefficient (offset);

**coefb** is the b coefficient to temperature; and

**coefc** is the c coefficient to salinity.

## 7.11 tco2_*.dat (Files 15–19)

These files provide the interpolated $TCO_2$ fields calculated annually and for each quarter (tco2_ann.dat, tco2_djf.dat, tco2_mam.dat, tco2_jja.dat, and tco2_son.dat). The files are sorted by longitude and latitude and can be read by using the following FORTRAN 77 code (contained in **tco2dat.for**, File 6):

```
      REAL lon, lat, dep, mld, trco2, tmp, aou, sal

      read (1, 10, end=999) lon, lat, dep, mld, trco2, tmp,
     1 aou, sal

 10   format (F7.1, 1X, F6.1, 1X, F7.1, 1X, F7.1, 1X, F9.1,
     1 1X, F7.3, 1X, F7.3, 1X, F7.3)
```

Stated in tabular form, the contents include the following:

| Variable | Variable type | Variable width | Starting column | Ending column |
|---|---|---|---|---|
| **lon** | Numeric | 7 | 1 | 7 |
| **lat** | Numeric | 6 | 9 | 14 |
| **dep** | Numeric | 7 | 16 | 22 |
| **mld** | Numeric | 7 | 24 | 30 |
| **tco2** | Numeric | 9 | 32 | 40 |
| **tmp** | Numeric | 7 | 42 | 48 |
| **aou** | Numeric | 7 | 50 | 56 |
| **sal** | Numeric | 7 | 58 | 64 |

The variables are defined as follows:

**lon** is the longitude for which $TCO_2$ was calculated;

**lat** is the latitude for which $TCO_2$ was calculated;

**dep** is the depth for which $TCO_2$ was calculated (m);

**mld** is the maximum layer depth (m);

**tco2** is the total carbon dioxide ($\mu$mol/kg);

**tmp** is the temperature (°C);

**aou** is the apparent oxygen utilization ($\mu$mol/kg); and

**sal** is the salinity.

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