WORLD OCEAN ATLAS 2023

Product Documentation

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For updates on the data, documentation, and additional information about the WOA23 please refer to:
https://www.ncei.noaa.gov/products/world-ocean-atlas

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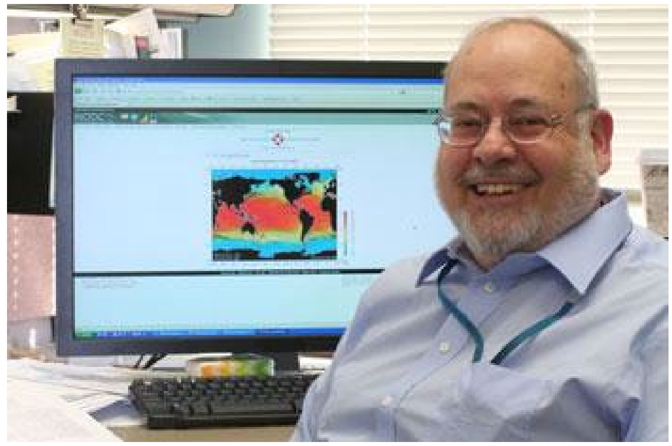
To Sydney (Syd) Levitus



Syd exemplifies the craft of careful, systematic inquiry of the large-scale distributions and low-frequency variability from seasonal-to-decadal time scales of ocean properties. He was one of the first to recognize the importance and benefits of creating objectively analyzed climatological fields of measured ocean variables including temperature, salinity, oxygen, nutrients, and derived fields such as mixed layer depth. Upon publishing *Climatological Atlas of the World Ocean* in 1982, he distributed this work without restriction, an act not common at the time. This seminal atlas moved the oceanographic diagnostic research from using hand-drawn maps to using objectively analyzed fields of ocean variables.

With his NODC (now NCEI) Ocean Climate Laboratory (OCL) colleagues, and unprecedented cooperation from the U.S. and international ocean scientific and data management communities, he created the *World Ocean Database (WOD)*; the world's largest collection of ocean profile data that are available internationally without restriction. The *World Ocean Atlas (WOA)* series represents the gridded objective analyses of the WOD and these fields have also been made available without restriction.

The WOD and WOA series are used so frequently that they have become known generically as the "Levitus Climatology". These databases and products enable systematic studies of ocean variability in its climatological context that were not previously possible. His foresight in creating WOD and WOA has been demonstrated by their widespread use over the years. Syd has made major contributions to the scientific and ocean data management communities. He has also increased public understanding of the role of the oceans in climate. He retired in 2013 after 39 years of distinguished civil service. He distilled the notion of the synergy between rigorous data management and science; there are no shortcuts.

All of us at the Ocean Climate Laboratory would like to once again dedicate this atlas to Syd, his legacy, vision, and mentorship.

The OCL Team

Acknowledgments

This work was made possible by a grant from the NOAA Climate and Global Change Program, which enabled the establishment of a research group at the National Oceanographic Data Center (now the National Centers for Environmental Information – NCEI). The purpose of this group is to prepare research quality oceanographic databases, as well as to compute objective analyses of, and diagnostic studies based on, these databases. Support is now from base funds and from the NOAA Climate Program Office.

The data on which this atlas is based are in *World Ocean Database 2023 (WOD)* and are distributed on-line by NCEI. Many data were acquired as a result of the IOC/IODE *Global Oceanographic Data Archaeology and Rescue* (GODAR) project and the IOC/IODE *World Ocean Database* project (WOD). Additionally, most of the subsurface ocean profiles over the past two decades in WOD are a result of the Argo program which has provided unprecedented observation coverage in both space and time of the near-global subsurface ocean.

The WOD is a composite of publicly available ocean profile data, both historical and recent. We acknowledge the scientists, technicians, and programmers who have collected and processed data, those individuals who have submitted data to national and regional data centers as well as the managers and staff at the various data centers. We are continuing to work on a more substantive and formalized way to acknowledge all those who have collected and contributed to oceanographic measurements, which were used to calculate the fields in the WOA. Until we have such a system in place, we direct the reader's attention to lists of primary investigators, institutions, and projects, which contributed data (codes can be used to locate data in the World Ocean Database). We also thank our colleagues at the NCEI. Their efforts have made this and similar works possible.

We dedicate this work to Carla Coleman who always contributed with a smile and was taken from us too soon.

World Ocean Atlas 2023 (WOA23) Product Documentation

Summary: This document describes the World Ocean Atlas 2023 (WOA23) statistical and objectively analyzed field data files. This description includes the types of statistical fields available, the oceanographic variables analyzed, and at which standard depth levels, time spans, time periods and grid resolutions they were analyzed. This description also includes the naming convention for the files, as well as the structure and format for the files. For a description of the data used, and the procedures for calculating WOA statistical fields, see https://www.ncei.noaa.gov/products/world-ocean-atlas

The World Ocean Atlas 2023 (WOA23) release – February 2024 – updates previous versions of the World Ocean Atlas to include approximately ~3.1 million new oceanographic casts added to the World Ocean Database (WOD) since the previous release (WOD18 & WOA18 – July 2019) as well as renewed and updated quality control. We would ask that if users of the atlas find any suspect features in WOA23, they please contact us (OCL.help@noaa.gov) with an explanation of the problem so we can investigate.

The following publications are released concurrently with the final version of WOA23. These publications are available at the WOA23 web: https://www.ncei.noaa.gov/access/world-ocean-atlas-2023/

Locarnini, R.A., A.V. Mishonov, O.K. Baranova, J.R. Reagan, T.P. Boyer, D. Seidov, Z. Wang, H.E. Garcia, C. Bouchard, S.L. Cross, C.R. Paver, and D. Dukhovskoy (2024). *World Ocean Atlas 2023, Volume 1: Temperature*. A. Mishonov Tech. Ed., NOAA Atlas NESDIS 89, 52 pp, https://doi.org/10.25923/54bh-1613

Reagan, J.R., D. Seidov, Z. Wang, D. Dukhovskoy, T.P. Boyer, R.A. Locarnini, O.K. Baranova, A.V. Mishonov, H.E. Garcia, C. Bouchard, S.L. Cross, and C.R. Paver. (2024). *World Ocean Atlas 2023, Volume 2: Salinity*. A. Mishonov, Tech. Ed., NOAA Atlas NESDIS 90, 51pp. https://doi.org/10.25923/70qt-9574

Garcia, H.E., Z. Wang, C. Bouchard, S.L. Cross, C.R. Paver, J.R. Reagan, T.P. Boyer, R.A. Locarnini, A.V. Mishonov, O. Baranova, D. Seidov, and D. Dukhovskoy (2024). *World Ocean Atlas 2023, Volume 3: Dissolved Oxygen, Apparent Oxygen Utilization, and Oxygen Saturation.* A. Mishonov, Tech. Ed., NOAA Atlas NESDIS 91, 34pp, https://doi.org/10.25923/rb67-ns53

Garcia, H.E., C. Bouchard, S.L. Cross, C.R. Paver, Z. Wang, J.R. Reagan, T.P. Boyer, R.A. Locarnini, A.V. Mishonov, O. Baranova, D. Seidov, and D. Dukhovskoy (2024). *World Ocean Atlas 2023, Volume 4: Dissolved Inorganic Nutrients (phosphate, nitrate, silicate)*. A. Mishonov, Tech. Ed., NOAA Atlas NESDIS 92, 34pp, https://doi.org/10.25923/39qw-7j08

Mishonov, A.V., T.P. Boyer, O.K. Baranova, C.N. Bouchard, S.L. Cross, H.E. Garcia, R.A. Locarnini, C.R. Paver, J.R. Reagan, Z. Wang, D. Seidov, A.I. Grodsky, J. Beauchamp (2024). *World Ocean Database 2023*. C. Bouchard, Technical Ed. NOAA Atlas NESDIS 97, DOI https://doi.org/10.25923/z885-h264 (in preparation).

- ## Available grid resolution

The World Ocean Atlas 2023 consists of objectively analyzed climatological mean fields on both quarter- and one-degree latitude/longitude grids. Statistical fields used in quality control (but not objectively analyzed climatological means) are available on a five-degree latitude/longitude grid.

- ## Available time spans and time periods

Time span refers to the years represented in the climatological mean and statistical fields. Time period refers to the divisions of a calendar year. The time periods are annual, seasonal (by three-month periods; Winter = January, February, and March; Spring, Summer, and Fall are the sequentially following three-month periods), and monthly. Time spans are mostly decadal (10 year) spans, but also include 'all', denoting all data used regardless of year, and 'decav', an average of all available (year specific) time spans. An objective analysis for a specific time period is considered to be representative of that time period for the given time span. **Table 1** lists all time spans that are part of WOA23.

Table 1. Time Spans for World Ocean Atlas 2023

Time Span	Abbreviation	Comment
1955 – 1964	5564	First decade with sufficient data for climatological mean fields
1965 – 1974	6574	
1975 – 1984	7584	
1985 – 1994	8594	
1995 – 2004	95A4	
2005 – 2014	A5B4	Global coverage of Argo floats from 2005
2015 – 2022	B5C2	8 year "decade"
1971 – 2000	decav71A0	30-year climate normal for 1971-2000
1981 – 2010	decav81B0	30-year climate normal for 1981-2010
1991 – 2020	decav91C0	30-year climate normal for 1991-2020
1955-2022	decav	Average of seven decadal means from 1955 to 2022.
All available years	all	Average of all available data. Refers to the 1965-2022 time span for dissolved oxygen (and related fields) and nutrients.

- ## Available fields

Table 2 presents the list of statistical fields and the grid resolutions at which the fields are available. Quarter-degree fields represent the world as 1440x720 quarter-degree longitude / latitude boxes. One-degree fields represent the world as 360x180 one-degree longitude / latitude boxes. Five-degree fields divide the world into 72x36 five-degree longitude / latitude boxes. Five-degree statistical fields are the fields used for standard deviation window checks to filter the data; data that pass these statistical checks are then used to calculate the quarter-degree and one-degree climatology fields.

Table 2. Available objectively analyzed and statistical fields

Field Name	Quarter-degree field calculated	One-degree field calculated	Five-degree field calculated	Field Type Code (for file names)
Objectively analyzed climatology	√	√		an
Statistical mean	√	√	√	mn
Number of observations	√	√	√	dd
Seasonal or monthly climatology minus annual climatology	√	√		ma
Standard deviation from statistical mean	√	√	√	sd
Standard error of the statistical mean	√	√	√	se
Statistical mean minus objectively analyzed climatology	√	√		oa
Number of mean values within radius of influence	√	√		gp
Objectively analyzed standard deviation	√	√		sdo
Standard error of the analysis	√	√		sea

Short description of the statistical fields in WOA23

- **Objectively analyzed climatologies** are the resulting mean fields for an oceanographic variable at standard depth levels for the World Ocean.
- The **statistical mean** is the average of all depth interpolated data values that pass quality control checks at each standard depth level for each variable in each quarter-degree, one-degree, or five-degree square which contain at least one measurement for the given oceanographic variable.
- The **number of observations** of each variable in each quarter-degree, one-degree, or five-degree square of the World Ocean at each standard depth level that pass quality control checks.
- The **standard deviation** about the statistical mean of each variable in each quarter-degree, one-degree, or five-degree square at each standard depth level that pass quality control checks.
- The **standard error of the mean** of each variable in each quarter-degree, one-degree, or five-degree square at each standard depth level that pass quality control checks.
- The **seasonal or monthly climatology minus the annual climatology** at each quarter-degree or one-degree square at each standard depth.
- The **statistical mean minus the climatological mean** at each quarter-degree or one-degree

square at each standard depth. This value is used as an estimate of interpolation and smoothing error.

- The **number of one-degree squares within the smallest radius of influence** around each quarter-degree or one-degree square that contain a statistical mean value.
- The **objectively analyzed standard deviation** are the resulting fields from objectively analyzing the standard deviation about the statistical mean fields. Only grid boxes that contain 6 or more observations are used in the objective analysis. *New for WOA23.*
- The **standard error of analysis** is one estimate of the uncertainty in the objective analysis. It is computed by calculating the standard error of the differences between the objectively analyzed and statistical mean fields within the 2^{nd} radius of influence (669km for one-degree, 267km for quarter-degree). A full description of this field and its calculation can be found in the supplement of Levitus *et al.* (2012). *New for WOA23.*

In addition to the statistical fields found in https://www.ncei.noaa.gov/data/oceans/woa/WOA23/DATA/ , there are two types of mask files (ending in suffix .msk). These files contain information used to calculate the statistical fields.

- The **landsea_XX.msk** contains the standard depth level number at which the bottom of the ocean is first encountered at each quarter-degree or one-degree square for the entire world. Land will have a value of 1, corresponding to the surface. Values of standard depth levels are listed in **Table 3**.
- The **basin_XX.msk** contains the basin code number defined for each grid square at each standard depth from the surface to 5500m. Each basin is identified by a code number that ranges from 1 to 60. The basin code number in a given quarter-degree and one-degree square may change with increased depth level. **Appendix 1** lists the geographic basin names, the code number associated with each basin, and the standard depth level at which the given basin is first encountered.

XX in the above mask names is either 01 (one-degree) or 04 (quarter-degree), depending on the resolution used to generate the land-sea and basin masks. These mask files are found at https://www.ncei.noaa.gov/data/oceans/woa/WOA23/MASKS/ .

• Available oceanographic variables.

The statistical fields were calculated for six oceanographic variables: temperature, salinity, dissolved oxygen, nitrate, phosphate, and silicate. Due to the irregularity in data in spatial and temporal distribution at various depths for different variables, not all variables were analyzed at all depths for all averaging periods (annual, individual seasons and months). **Table 4** lists the depth limits for each variable for each averaging period.

Temperature and Salinity fields are available on *one-degree* and *quarter-degree* grids as follow:

- ***One-degree* annual, seasonal, and monthly fields are available for 5564, 6574, 7584, 8594, 95A4, A5B4, B5C2, 'decav71A0', 'decav81B0', 'decav91C0', and 'decav' time spans;**
- ***Quarter-degree* annual and seasonal fields are available for 5564, 6574, 7584, 8594, 95A4, A5B4, B5C2, 'decav71A0', 'decav81B0', 'decav91C0', and 'decav' time spans;**

- ***Quarter-degree* monthly fields are ONLY available for A5B4, B5C2, 'decav71A0', 'decav81B0', 'decav91C0', and 'decav' time spans;**

***One-degree* and *quarter-degree* Temperature and Salinity fields are NOT available for the 'all' time span.**

Dissolved Oxygen (and related O2 fields) are available on a *one-degree* grid and for the 'decav71A0' and 'all' time span.

Nitrate, Phosphate, and Silicate fields are available ONLY for *one-degree* grid and for the 'all' time span.

The 'all' time span for oxygen and inorganic nutrients is the time span from 1965-2022.
***Five-degree* grid statistics are available only for the 'all' time span.**

Table 3. Depths associated with each standard level number.
The maximum depth of the WOA23 is 5500 m (Table 4).

Depth (m)	Level	Depth (m)	Level	Depth (m)	Level	Depth (m)	Level
0	1	475	36	2300	70	5700	104
5	2	500	37	2400	71	5800	105
10	3	550	38	2500	72	5900	106
15	4	600	39	2600	73	6000	107
20	5	650	40	2700	74	6100	108
25	6	700	41	2800	75	6200	109
30	7	750	42	2900	76	6300	110
35	8	800	43	3000	77	6400	111
40	9	850	44	3100	78	6500	112
45	10	900	45	3200	79	6600	113
50	11	950	46	3300	80	6700	114
55	12	1000	47	3400	81	6800	115
60	13	1050	48	3500	82	6900	116
65	14	1100	49	3600	83	7000	117
70	15	1150	50	3700	84	7100	118
75	16	1200	51	3800	85	7200	119
80	17	1250	52	3900	86	7300	120
85	18	1300	53	4000	87	7400	121
90	19	1350	54	4100	88	7500	122
95	20	1400	55	4200	89	7600	123
100	21	1450	56	4300	90	7700	124
125	22	1500	57	4400	91	7800	125
150	23	1550	58	4500	92	7900	126
175	24	1600	59	4600	93	8000	127
200	25	1650	60	4700	94	8100	128
225	26	1700	61	4800	95	8200	129
250	27	1750	62	4900	96	8300	130
275	28	1800	63	5000	97	8400	131
300	29	1850	64	5100	98	8500	132
325	30	1900	65	5200	99	8600	133
350	31	1950	66	5300	100	8700	134
375	32	2000	67	5400	101	8800	135
400	33	2100	68	5500	102	8900	136
425	34	2200	69	5600	103	9000	137
450	35						

Table 4. Depth ranges and standard depth levels numbers for annual, seasonal, and monthly statistics of each available oceanographic variable.

One-letter codes are first letter of file names for given variable.

Oceanographic Variable (one-letter code)	Depths for Annual Climatology	Depths for Seasonal Climatology	Depths for Monthly Climatology
Temperature (**t**)	0-5500 meters (102 levels)	0-5500 meters (102 levels)	0-1500 meters (57 levels)
Salinity (**s**)	0-5500 meters (102 levels)	0-5500 meters (102 levels)	0-1500 meters (57 levels)
Oxygen (**o**)	0-5500 meters (102 levels	0-1500 meters (57 levels)	0-1500 meters (57 levels)
Nitrate (**n**)	0-5500 meters (102 levels)	0-800 meters (43 levels)	0-800 meters (43 levels)
Phosphate (**p**)	0-5500 meters (102 levels)	0-800 meters (43 levels)	0-800 meters (43 levels)
Silicate (**i**)	0-5500 meters (102 levels)	0-800 meters (43 levels)	0-800 meters (43 levels)

• Data formats

WOA23 data files are available in four formats:

- Climate and Forecast (CF) compliant Network Common Data Format (NetCDF),
- Comma-separated value (csv) format,
- ArcGIS-compatible shapefiles,
- Compact grid format (a legacy WOA ASCII format)

Appendix 2 gives an example of the csv format and **Appendix 3** gives an example of the structure of the NetCDF file. The legacy ASCII format files are provided for applications that have been set up to read this format in previous WOA releases. Usage of this format is not encouraged, as it does not explicitly give depth, possibly resulting in confusion when reading WOA23 files in software set up for previous releases of World Ocean Atlas, or vice-versa.

For information regarding to the legacy WOA ASCII format, please see https://www.nodc.noaa.gov/OC5/WOD/wod-woa-faqs.html . Each csv file contains all depths for a single statistical field; please note that this differs from the csv files released for WOA23.

• File naming convention

All files, except those in NetCDF format, follow the same naming convention:

woa23_[DECA]_[v][tp][ft][gr].[form_end]

while NetCDF files, which contain all statistical fields for a given time span, variable, time period, and grid resolution in a single file, are named,

woa23_[DECA]_[v][tp]_[gr].[form_end]

Where:

[DECA] represents decade, the time span (years) represented by the objectively analyzed means and other statistical fields as listed in **Table 1**:

[v] represents the oceanographic variable using one-letter code as listed in **Table 4**;

[tp] represents the averaging period, two-digit code as follows:

00 – annual statistics, all data used;
01 to 12 – monthly statistics (starting with 01 – January, to 12 – December);
13 to 16 – seasonal statistics:
Season 13 – North Hemisphere winter (January - March);
Season 14 – North Hemisphere spring (April - June);
Season 15 – North Hemisphere summer (July - September);
Season 16 – North Hemisphere autumn (October - December);

[ft] represents field type, describing the calculated statistic represented in the file, as listed in **Table 2**

[gr] represents the grid size, two-digit code as follows:

04 – quarter-degree grid resolution
01 – one-degree grid resolution
5d – five-degree grid resolution

[form_end] format suffix (filename extension), dependent on format as follows:

csv – comma-separated value format
nc – netCDF format
dbf, shp, shx – shapefiles (when downloaded will be in a **.tar** file together)
dat – compact grid data format (legacy WOA ASCII format)

Examples:

woa23_95A4_s02an01.csv is a file containing World Ocean Atlas 2023, February objectively analyzed salinity on one-degree grid resolution for the years 1995-2004 in comma-separated value format;

woa23_A5B4_t13_04.nc is a file containing World Ocean Atlas 2023, Winter objectively analyzed and statistical fields of temperature on a quarter-degree grid resolution for the years 2005-2014 in NetCDF format.

• Utilities

Folder **utils** contains decompression freeware: **gzip124.exe** – self-extracting *DOS* executable, and **gzip124.tar** – a compressed file containing source code for *UNIX* users.

A. Installing **gzip** for the first time

DOS Users: The file **gzip124.exe** is a self-extracting DOS executable.

Copy **gzip124.exe** to your hard drive,

Run **gzip124.exe** and use the file **gzip.exe** to uncompress data as described in Section **B**.

UNIX Users:

Copy **gzip124.tar** to your UNIX system

Run the following command: **tar -xvf gzip124.tar**

This command will create a directory named **gzip-1.2.4** that includes the **gzip** source code and documentation about copyrights, compression methods and how to compile and install the **gzip** code. Read through the README file and when ready to build the **gzip** executable, follow instructions in the INSTALL file.

B. Decompressing data from WOA

To decompress the WOA files, it is recommended to first copy the data files to a hard disk. Use **gzip** to decompress selected files or a directory and all subdirectories with one command. The **gzip** utility has a limited help menu accessible with the **-h** option (e.g. **gzip -h**); additional information may be found at www.gzip.org.

To decompress a single file:

gzip -nd <filename>

To decompress the contents of a directory and all of its subdirectories:

gzip -ndr <directoryname>

If an older version of gzip is used, the -n option is required in order to preserve the correct file names.

Appendix 1. Basins defined for objective analysis and the shallowest standard depth level for which each basin is defined.

#	Basin[1]	Standard Depth Level	#	Basin[1]	Standard Depth Level
1	Atlantic Ocean	1*	31	West European Basin	82
2	Pacific Ocean	1*	32	Southeast Indian Basin	82
3	Indian Ocean	1*	33	Coral Sea	82
4	Mediterranean Sea	1*	34	East Indian Basin	82
5	Baltic Sea	1	35	Central Indian Basin	82
6	Black Sea	1	36	Southwest Atlantic Basin	82
7	Red Sea	1	37	Southeast Atlantic Basin	82
8	Persian Gulf	1	38	Southeast Pacific Basin	82
9	Hudson Bay	1	39	Guatemala Basin	82
10	Southern Ocean	1*	40	East Caroline Basin	87
11	Arctic Ocean	1	41	Marianas Basin	87
12	Sea of Japan	1	42	Philippine Sea	87
13	Kara Sea	22	43	Arabian Sea	87
14	Sulu Sea	25	44	Chile Basin	87
15	Baffin Bay	37	45	Somali Basin	87
16	East Mediterranean	41	46	Mascarene Basin	87
17	West Mediterranean	47	47	Crozet Basin	87
18	Sea of Okhotsk	47	48	Guinea Basin	87
19	Banda Sea	55	49	Brazil Basin	92
20	Caribbean Sea	55	50	Argentine Basin	92
21	Andaman Basin	62	51	Tasman Sea	87
22	North Caribbean	67	52	Atlantic Indian Basin	92
23	Gulf of Mexico	67	53	Caspian Sea	1
24	Beaufort Sea	77	54	Sulu Sea II	37
25	South China Sea	77	55	Venezuela Basin	37
26	Barents Sea	77	56	Bay of Bengal	1*
27	Celebes Sea	62	57	Java Sea	16
28	Aleutian Basin	77	58	East Indian Atlantic Basin	97
29	Fiji Basin	82	59	Chiloe	1
30	North American Basin	82	60	Bransfield Strait	37

[1]Basins marked with a "*" can interact with adjacent basins in the objective analysis.

Appendix 2. Sample from csv file format

File=woa23_95A4_t00an01.csv (showing only the first 8 lines of the file)

```
#WOA23 one-degree ANNUAL temperature Climatological mean
#COMMA SEPARATED LATITUDE, LONGITUDE, AND VALUES AT DEPTHS
(M):0,5,10,15,20,25,30,35,40,45,50,55,60,65,70,75,80,85,90,95,100,125,150
,175,200,225,250,275,300,325,350,375,400,425,450,475,500,550,600,650,700,750,800,850,900,950,100
0,1050,1100,1150,1200,1250,1300,1350
,1400,1450,1500,1550,1600,1650,1700,1750,1800,1850,1900,1950,2000,2100,2200,2300,2400,2500,26
00,2700,2800,2900,3000,3100,3200,3300,3
400,3500,3600,3700,3800,3900,4000,4100,4200,4300,4400,4500,4600,4700,4800,4900,5000,5100,5200
,5300,5400,5500
-77.500,-178.500,-1.372,-1.393,-1.420,-1.437,-1.456,-1.486,-1.540,-1.590,-1.624,-1.659,-1.688,-1.711,-
1.729,-1.744,-1.757,-1.771,-1.
783,-1.790,-1.793,-1.793,-1.793,-1.776,-1.760,-1.738,-1.716,-1.680,-1.715,-1.753,-1.810,-1.847,-1.899,-
1.935,-1.968,-2.022,-2.036,-2
.038,-2.063,-1.955,-1.892
-77.500,-177.500,-1.405,-1.415,-1.434,-1.451,-1.459,-1.479,-1.538,-1.593,-1.629,-1.665,-1.693,-1.717,-
1.738,-1.755,-1.766,-1.778,-1.
787,-1.789,-1.795,-1.802,-1.801,-1.791,-1.781,-1.762,-1.752,-1.732,-1.765,-1.799,-1.839,-1.865,-1.905,-
1.941,-1.970,-2.021,-2.034,-2
.038,-2.065,-1.960,-1.905
-77.500,-176.500,-1.387,-1.417,-1.447,-1.462,-1.466,-1.484,-1.536,-1.592,-1.632,-1.668,-1.697,-1.722,-
1.745,-1.764,-1.775,-1.790,-1.
798,-1.804,-1.809,-1.812,-1.811,-1.807,-1.802,-1.787,-1.783,-1.765,-1.790,-1.822,-1.851,-1.871,-1.908,-
1.943,-1.968,-2.019,-2.031,-2
.038,-2.065,-1.959,-1.916,-0.910
-77.500,-175.500,-1.397,-1.415,-1.444,-1.471,-1.490,-1.512,-1.557,-1.607,-1.645,-1.683,-1.712,-1.738,-
1.759,-1.774,-1.787,-1.802,-1.
810,-1.819,-1.827,-1.827,-1.822,-1.824,-1.825,-1.812,-1.812,-1.798,-1.815,-1.841,-1.860,-1.874,-1.907,-
1.939,-1.964,-2.015,-2.026,-2
.037,-2.065,-1.958,-1.927
-77.500,-174.500,-1.385,-1.415,-1.453,-1.484,-1.509,-1.535,-1.580,-1.634,-1.671,-1.704,-1.730,-1.755,-
1.773,-1.791,-1.806,-1.818,-1.
823,-1.827,-1.832,-1.835,-1.834,-1.841,-1.844,-1.832,-1.837,-1.824,-1.835,-1.857,-1.868,-1.874,-1.901,-
1.928,-1.959,-2.008,-2.019,-2
.033,-2.063,-1.954,-1.941
-77.500,-173.500,-1.332,-1.397,-1.453,-1.498,-1.530,-1.565,-1.607,-1.657,-1.692,-1.719,-1.744,-1.766,-
1.782,-1.802,-1.815,-1.827,-1.
835,-1.836,-1.840,-1.844,-1.844,-1.858,-1.862,-1.852,-1.860,-1.847,-1.853,-1.870,-1.875,-1.872,-1.892,-
1.912,-1.951,-1.997,-2.012,-2
.028,-2.058,-1.947
```

Appendix 3. Sample from netCDF file format

```
netcdf woa23_B5C2_s01_01 {
dimensions:
	nbounds = 2 ;
	lat = 180 ;
	lon = 360 ;
	depth = 57 ;
	time = 1 ;
variables:
	int crs ;
		crs:grid_mapping_name = "latitude_longitude" ;
		crs:epsg_code = "EPSG:4326" ;
		crs:longitude_of_prime_meridian = 0.f ;
		crs:semi_major_axis = 6378137.f ;
		crs:inverse_flattening = 298.2572f ;
	float lat(lat) ;
		lat:standard_name = "latitude" ;
		lat:long_name = "latitude" ;
		lat:units = "degrees_north" ;
		lat:axis = "Y" ;
		lat:bounds = "lat_bnds" ;
	float lat_bnds(lat, nbounds) ;
		lat_bnds:comment = "latitude bounds" ;
	float lon(lon) ;
		lon:standard_name = "longitude" ;
		lon:long_name = "longitude" ;
		lon:units = "degrees_east" ;
		lon:axis = "X" ;
		lon:bounds = "lon_bnds" ;
	float lon_bnds(lon, nbounds) ;
		lon_bnds:comment = "longitude bounds" ;
	float depth(depth) ;
		depth:standard_name = "depth" ;
		depth:bounds = "depth_bnds" ;
		depth:positive = "down" ;
		depth:units = "meters" ;
		depth:axis = "Z" ;
	float depth_bnds(depth, nbounds) ;
		depth_bnds:comment = "depth bounds" ;
	float time(time) ;
		time:standard_name = "time" ;
		time:long_name = "time" ;
		time:units = "months since 2015-01-01 00:00:00" ;
		time:axis = "T" ;
		time:climatology = "climatology_bounds" ;
	float climatology_bounds(time, nbounds) ;
		climatology_bounds:comment = "This variable defines the bounds of the climatological time
period for each time" ;
	float s_an(time, depth, lat, lon) ;
		s_an:standard_name = "sea_water_practical_salinity" ;
		s_an:long_name = "Objectively analyzed mean fields for sea_water_practical_salinity at
standard depth levels." ;
		s_an:coordinates = "time lat lon depth" ;
```

```
		s_an:cell_methods = "area: mean depth: mean time: mean within years time: mean over years"
;
		s_an:grid_mapping = "crs" ;
		s_an:units = "1" ;
		s_an:_FillValue = 9.96921e+36f ;
	float s_mn(time, depth, lat, lon) ;
		s_mn:standard_name = "sea_water_practical_salinity" ;
		s_mn:long_name = "Average of all unflagged interpolated values at each standard depth level
for sea_water_practical_salinity in each grid-square which contain at least one measurement." ;
		s_mn:coordinates = "time lat lon depth" ;
		s_mn:cell_methods = "area: mean depth: mean time: mean within years time: mean over years"
;
		s_mn:grid_mapping = "crs" ;
		s_mn:units = "1" ;
		s_mn:_FillValue = 9.96921e+36f ;
	int s_dd(time, depth, lat, lon) ;
		s_dd:standard_name = "sea_water_practical_salinity number_of_observations" ;
		s_dd:long_name = "The number of observations of sea_water_practical_salinity in each grid-
square at each standard depth level." ;
		s_dd:coordinates = "time lat lon depth" ;
		s_dd:cell_methods = "area: sum depth: point time: sum" ;
		s_dd:grid_mapping = "crs" ;
		s_dd:units = "1" ;
		s_dd:_FillValue = -32767 ;
	float s_sd(time, depth, lat, lon) ;
		s_sd:long_name = "The standard deviation about the statistical mean of
sea_water_practical_salinity in each grid-square at each standard depth level." ;
		s_sd:coordinates = "time lat lon depth" ;
		s_sd:cell_methods = "area: mean depth: mean time: standard_deviation" ;
		s_sd:grid_mapping = "crs" ;
		s_sd:units = "1" ;
		s_sd:_FillValue = 9.96921e+36f ;
	float s_se(time, depth, lat, lon) ;
		s_se:standard_name = "sea_water_practical_salinity standard_error" ;
		s_se:long_name = "The standard error about the statistical mean of
sea_water_practical_salinity in each grid-square at each standard depth level." ;
		s_se:coordinates = "time lat lon depth" ;
		s_se:cell_methods = "area: mean depth: mean time: mean" ;
		s_se:grid_mapping = "crs" ;
		s_se:units = "1" ;
		s_se:_FillValue = 9.96921e+36f ;
	float s_oa(time, depth, lat, lon) ;
		s_oa:standard_name = "sea_water_practical_salinity" ;
		s_oa:long_name = "statistical mean value minus the objectively analyzed mean value for
sea_water_practical_salinity." ;
		s_oa:coordinates = "time lat lon depth" ;
		s_oa:cell_methods = "area: mean depth: mean time: mean with years time: mean over years" ;
		s_oa:grid_mapping = "crs" ;
		s_oa:units = "1" ;
		s_oa:_FillValue = 9.96921e+36f ;
	float s_ma(time, depth, lat, lon) ;
		s_ma:standard_name = "sea_water_practical_salinity" ;
		s_ma:long_name = " The objectively analyzed value for the given time period minus the
objectively analyzed annual mean value for sea_water_practical_salinity." ;
```

```
        s_ma:coordinates = "time lat lon depth" ;
        s_ma:cell_methods = "area: mean depth: mean time: mean within years time: mean over years"
;
        s_ma:grid_mapping = "crs" ;
        s_ma:units = "1" ;
        s_ma:_FillValue = 9.96921e+36f ;
    int s_gp(time, depth, lat, lon) ;
        s_gp:long_name = "The number of grid-squares within the smallest radius of influence around
each grid-square which contain a statistical mean for sea_water_practical_salinity." ;
        s_gp:coordinates = "time lat lon depth" ;
        s_gp:cell_methods = "area: mean depth: mean time: mean within years time: mean over years"
;
        s_gp:grid_mapping = "crs" ;
        s_gp:units = "1" ;
        s_gp:_FillValue = -32767 ;
    float s_sdo(time, depth, lat, lon) ;
        s_sdo:standard_name = "sea_water_practical_salinity" ;
        s_sdo:long_name = "Objectively analyzed standard deviation fields for
sea_water_practical_salinity at standard depth levels." ;
        s_sdo:coordinates = "time lat lon depth" ;
        s_sdo:cell_methods = "area: mean depth: mean time: mean" ;
        s_sdo:grid_mapping = "crs" ;
        s_sdo:units = "1" ;
        s_sdo:_FillValue = 9.96921e+36f ;
    float s_sea(time, depth, lat, lon) ;
        s_sea:standard_name = "sea_water_practical_salinity" ;
        s_sea:long_name = "The standard error about the objectively analyzed data of
sea_water_practical_salinity defined in Levitus et al. (2012) GRL." ;
        s_sea:coordinates = "time lat lon depth" ;
        s_sea:cell_methods = "area: mean depth: mean time: mean" ;
        s_sea:grid_mapping = "crs" ;
        s_sea:units = "1" ;
        s_sea:_FillValue = 9.96921e+36f ;

// global attributes:
        :Conventions = "CF-1.6" ;
        :title = "World Ocean Atlas 2023 : sea_water_practical_salinity January 2015-2022 1.00
degree" ;
        :summary = "Climatological mean salinity for the global ocean from in situ profile data" ;
        :references = "Reagan, J.R., D. Seidov, Z. Wang, D. Dukhovskoy, T.P. Boyer, R.A. Locarnini,
O.K. Baranova, A.V. Mishonov, H.E. Garcia, C. Bouchard, S.L. Cross, and C.R. Paver (2023). World
Ocean Atlas 2023, Volume 2: Salinity. A. Mishonov Technical Editor, NOAA Atlas NESDIS 90,
https://doi.org/10.25923/70qt-9574." ;
        :institution = "NOAA National Centers for Environmental Information (NCEI)" ;
        :comment = "Global Climatology as part of the World Ocean Atlas Project" ;
        :id = "woa23_B5C2_s01_01.nc" ;
        :naming_authority = "gov.noaa.ncei" ;
        :time_coverage_start = "2015-01-01" ;
        :time_coverage_duration = "P08Y" ;
        :time_coverage_resolution = "P01M" ;
        :geospatial_lat_min = -90.f ;
        :geospatial_lat_max = 90.f ;
        :geospatial_lon_min = -180.f ;
        :geospatial_lon_max = 180.f ;
```

```
		:geospatial_vertical_min = 0.f ;
		:geospatial_vertical_max = 1500.f ;
		:geospatial_lat_units = "degrees_north" ;
		:geospatial_lat_resolution = "1.00 degrees" ;
		:geospatial_lon_units = "degrees_east" ;
		:geospatial_lon_resolution = "1.00 degrees" ;
		:geospatial_vertical_units = "m" ;
		:geospatial_vertical_resolution = "" ;
		:geospatial_vertical_positive = "down" ;
		:creator_name = "Ocean Climate Laboratory Team" ;
		:creator_email = "NCEI.Info@noaa.gov" ;
		:creator_url = "http://www.ncei.noaa.gov" ;
		:project = "World Ocean Atlas" ;
		:processing_level = "processed" ;
		:keywords = "<ISO_TOPIC_Category> Oceans</ISO_TOPIC_Category> Oceans > Ocean
Salinity" ;
		:keywords_vocabulary = "ISO 19115, GCMD" ;
		:standard_name_vocabulary = "CF-1.6" ;
		:contributor_name = "Ocean Climate Laboratory" ;
		:contributor_role = "Calculation of climatologies" ;
		:featureType = "Grid" ;
		:cdm_data_type = "Grid" ;
		:publisher_name = "National Centers for Environmental Information (NCEI)" ;
		:publisher_url = "http://www.ncei.noaa.gov/" ;
		:publisher_email = "NCEI.Info@noaa.gov" ;
		:ncei_template_version = "NCEI_NetCDF_Grid_Template_v1.0" ;
		:license = "These data are openly available to the public. Please acknowledge the use of these
data with the text given in the acknowledgment attribute." ;
		:Metadata_Conventions = "Unidata Dataset Discovery v1.0" ;
		:metadata_link = "https://www.ncei.noaa.gov/products/world-ocean-atlas" ;
		:date_created = "2024-01-28 " ;
		:date_modified = "2024-01-28 " ;
		:_NCProperties = "version=2,netcdf=4.9.2,hdf5=1.14.3" ;
}
```