



# DATA PRODUCT SPECIFICATION FOR CONDUCTIVITY

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**Document Control Sheet**

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### Signature Page

This document has been reviewed and approved for release to Configuration Management.

OOI Senior Systems Engineer:



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This document has been reviewed and meets the needs of the OOI Cyberinfrastructure for the purpose of coding and implementation.

OOI CI Signing Authority:



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## 1 Abstract

This document describes the computation used to calculate the OOI Level 1 Conductivity core data product, which is calculated using data from the Sea-Bird Electronics conductivity, temperature and depth (CTD) family of instruments. This document is intended to be used by OOI programmers to construct appropriate processes to create the L1 conductivity product.

## 2 Introduction

### 2.1 Author Contact Information

Please contact Lorraine Heilman ([lheilman@oceanleadership.org](mailto:lheilman@oceanleadership.org)), Sarah Webster ([swebster@oceanleadership.org](mailto:swebster@oceanleadership.org)) or the Data Product Specification lead ([DPS@lists.oceanobservatories.org](mailto:DPS@lists.oceanobservatories.org)) for more information concerning this document.

### 2.2 Metadata Information

#### 2.2.1 Data Product Name

The OOI Core Data Product Name for this data product is

- CONDWAT

The OOI Core Data Product Descriptive Name for this data product is

- Conductivity

#### 2.2.2 Data Product Abstract (for Metadata)

The OOI Level 1 Conductivity data product is computed by converting raw hexadecimal conductivity data from the conductivity, temperature and depth (CTD) family of instruments into Siemens/meter.

#### 2.2.3 Computation Name

Not required for data product algorithms.

#### 2.2.4 Computation Abstract (for Metadata)

This algorithm computes the OOI Level 1 Conductivity data product, which is calculated by converting raw hexadecimal conductivity data from the conductivity, temperature and depth (CTD) family of instruments into Siemens/meter.

#### 2.2.5 Instrument-Specific Metadata

There are no instrument-specific metadata that need to be added for the algorithm.

#### 2.2.6 Synonyms

None.

#### 2.2.7 Similar Data Products

Similar products that this may be confused with are

- Practical Salinity

## 2.3 Instruments

The CTD Processing Flow document (DCN 1342-00001) describes the instrument classes and make/models that produce the data from which the L1 conductivity data product is calculated. This document also describes the flow of data from the CTDs through all of the relevant QC, calibration, and data product algorithms.

Note that the raw data from the GPCTD make/model—the CTDs on board the gliders and autonomous underwater vehicles (AUVs)—are processed onboard the vehicles with proprietary software from the vehicle vendors. These data are presented already in decimal format in appropriate units (°C, Siemens/meter, decibars), therefore processing raw hexadecimal data from the CTDGP is not included in the algorithm described in this document.

Please see the Instrument Application in the SAF for specifics of instrument locations and platforms.

## 2.4 Literature and Reference Documents

IOC, et al. (2010). The international thermodynamic equation of seawater-2010: Calculation and use of thermodynamic properties, UNESCO.

Sea-Bird (2009), SBE 16*plus* V2 SEACAT User's Manual. Manual Version #005.

Sea-Bird (2011), SBE 37-IM MicroCAT User's Manual. Manual Version #027.

Sea-Bird (2010), Application Note 31. Computing Temperature and Conductivity Slope and Offset Correction Coefficients from Laboratory Calibrations and Salinity Bottle Samples. Revision February 2010. Sea-Bird Electronics, Inc.

Sea-Bird (2008), Application Note 10. Compressibility Compensation of Sea-Bird Conductivity Sensors. Revision March 2008. Sea-Bird Electronics, Inc.

## 2.5 Terminology

### 2.5.1 Definitions

The following terms are defined here for use throughout this document. Definitions of general OOI terminology are contained in the Level 2 Reference Module in the OOI requirements database (DOORS).

No terms need defining.

### 2.5.2 Acronyms, Abbreviations and Notations

General OOI acronyms, abbreviations and notations are contained in the Level 2 Reference Module in the OOI requirements database (DOORS).

There are no other acronyms, abbreviations, or notations for this document.

### 2.5.3 Variables and Symbols

The following variables and symbols are defined here for use throughout this document.

C_L1	L1 conductivity data product [S/m]
C <sub>dec</sub> , C_dec	Raw instrument conductivity data in decimal
C <sub>hex</sub> , C_hex	Raw instrument conductivity data in hexadecimal
f_hz	Conductivity frequency data in Hz

f                      Conductivity frequency data in kHz  
L1\_T                L1 TEMPWAT temperature data product  
L1\_P                L1 PRESWAT pressure data product  
g, h, i, j, CPcor, CTcor              CTD calibration coefficients

### **3 Theory**

#### **3.1 Description**

Water conductivity is one of the variables directly measured by CTD instruments and is calculated from the raw hexadecimal data provided by the instrument. The SBE 16plusV2 model will output "raw frequencies and voltages in hexadecimal" as it is referred to in the Sea-Bird manuals. The 37IM model will output "engineering units in Hex". This requires that the L0 conductivity data product output from the CTD driver, which is a hexadecimal string, to be converted to decimal and scaled according to the CTD manual (different for each CTD make/model). Conversion and scaling (described herein) results in conductivity in S/m based on factory calibration of conductivity. Note that conductivity calibration scales with pressure and are handled in the Conductivity Compensation DPS (DCN 1341-10030). See Sea-Bird App Note 10 (2008) for more details. This is because conductivity cells measure the conductance of a specific geometry of seawater within the conductivity cell and the ratio of the length of the cell to the cross sectional area will be deformed slightly with changes to the ambient pressure surrounding the cell.

#### **3.2 Mathematical Theory**

The CTD is received by OOI calibrated from Sea-Bird before its initial deployment. Post-initial deployment calibration checks and/or recalibrations will be performed at Sea-Bird. The factory-calibrated conductivity is scaled into efficient, memory-saving hexadecimal string aboard the CTD instrument. This hexadecimal string, after it is separated from the rest of the data stream by the CTD driver, is the L0 conductivity data product. The parsing instructions for the instrument hexadecimal string can be found in Appendix A.

The L1 conductivity data product algorithm takes the L0 conductivity data product and converts it into Siemens per meter (S/m). Once the hexadecimal conductivity string is converted to decimal, several simple calculations are necessary to produce the correct decimal floating representation of the data in Siemens per meter (S/m). The conversion differs by CTD make/model as described in Section 4.3.

#### **3.3 Known Theoretical Limitations**

None.

#### **3.4 Revision History**

None.

### **4 Implementation**

#### **4.1 Overview**

The conversion from the L0 conductivity data product to the L1 conductivity data product consists of a simple conversion from hex to decimal and a scaling operation. Existing code to perform these operations is not available, but modified examples from the CTD manuals are provided herein.

## 4.2 Inputs

### Inputs

- L0 CONDWAT (C\_hex) – conductivity as a hexadecimal string

Additional inputs for SBE 16plus V2 only:

- L1 TEMPWAT (L1\_T) – temperature converted to degrees Celcius
- L1 PRESWAT (L1\_P) – pressure converted to decibar
- g, h, i, j, CPcor, CTor calibration coefficients (originally from instrument calibration sheet, available from the metadata of the L0 CONDWAT data product)

### Input Data Formats

L0 conductivity data product is a hexadecimal string, the number of digits varies by instrument make/model:

**SBE 16plus V2** (Output Format 0) 6-character hex string (*applies to all 16plus V2, running either its native firmware or the 19plus V2 firmware*)

**SBE 37IM** (Output Format 0) 5-character hex string

## 4.3 Processing Flow

The specific steps necessary to create all calibrated and quality controlled data products for the CTD are described in the CTD Processing Flow document (DCN 1342-00001). This processing flow document contains a flow diagram showing all of the specific algorithms (data product and QC) necessary to compute all data products from the CTD and the order that the algorithms must be applied. Note that there is a conductivity compressibility calibration algorithm and secondary calibration algorithm routine that must be applied to the L1 conductivity data product in order to produce a scientifically useful value. These algorithms are called out in the CTD Processing Flow document mentioned above and described in detail in separate ATBD documents (DCN 1341-10030).

The processing flow for the conductivity algorithm code is as follows:

**SBE 16plus V2** Output Format 0 (running either its native firmware or the 19plus V2 firmware)  
output Format 1

- 1) Standard conversion from 6-character hex string (C\_hex) to decimal (C\_dec)
- 2) Calculate frequency in Hz  $f_{Hz} = C_{dec} / 256$
- 3) Calculate f in kHz:  $f = f_{Hz} / 1000$
- 4) Calculate C\_L1:  $C_{L1} = (g + h \cdot f^2 + i \cdot f^3 + j \cdot f^4) / (1 + CTcor \cdot L1\_T + CPcor \cdot L1\_P)$   
[Siemens/meter]

where g, h, i, j, CTcor, and CPcor are calibration coefficients provided on individual instrument calibration sheets and stored as metadata; t is the associated L1 TEMPWAT measurement [°C], and p is the associated L1 PRESWAT measurement [dbar].

**SBE 37IM** Output Format 0

- 1) Standard conversion from 5-character hex string (C\_hex) to decimal (C\_dec)
- 2) Scaling:  $C_{L1} [S/m] = (C_{dec} / 100,000) - 0.5$

The final product C\_L1 is the L1 conductivity data product in Siemens/meter.

Examples taken from the CTD manuals are included in Appendix A.

## 4.4 Outputs

The outputs of the conductivity algorithm are

- *In situ* water conductivity (C\_L1) in Siemens per meter [S/m] as a floating point number with six decimal places %.6f



The metadata that must be included with the output of this algorithm are

- There is no additional metadata that need to be included with this data product

See Appendix B for a discussion of the accuracy of the algorithm output.

## 4.5 Computational and Numerical Considerations

### 4.5.1 Numerical Programming Considerations

There are no numerical programming considerations for this computation. No special numerical methods are used.

### 4.5.2 Computational Requirements

Not applicable, this algorithm is not computationally intensive.

## 4.6 Code Verification and Test Data Sets

The code will be verified using the test data set provided, which contains inputs and their associated correct outputs. CI will verify that the code is correct by checking that the output, generated using the test data inputs, is identical to the test data conductivity output.

The test data sets below provide paired input and output data from both CTD models, which would be characteristic of a typical water column.

A spreadsheet (CTD16plusv2\_outputformat0\_v2.xls) that can be used to verify all calculations for the 16plusV2 data is included with references in the DPS Artifacts folder on Alfresco, along with a copy of the 16plusV2 calibration sheet (SVE+16plusV2+SEACAT+RS232+SN+16P66805-6943.pdf): Alfresco (<https://alfresco.oceanobservatories.org>)

REFERENCE > Data product Specification Artifacts > 1341-00020\_CONDWAT

SBE 37-IM Test Data	
Inputs	Output
raw conductivity in hex	Conductivity [S/m]
5CC60	3 . 3
55730	3 . 0
4E200	2 . 7
46CD0	2 . 4
3F7A0	2 . 1
3826F	1 . 8
30D40	1 . 5
29810	1 . 2
222E0	0 . 9
1ADB0	0 . 6
13880	0 . 3
0C350	0 . 0

SBE 16plus V2 Test Data*						
rawHex	L1_T (ITS-90 °C)	L1_C (S/m)	P (psi) interim calc.	L1_P (dbar)	thermistor T (°C)	
0461FC0A609208064F591F	18.9288	0.005771	0.225	0.158	18.55	
0461FD0A609208064F591F	18.9287	0.005771	0.225	0.158	18.55	
0461FC0A609208064F591F	18.9288	0.005771	0.225	0.158	18.55	
03CCC50A67860801B35E7B	22.4892	0.010898	-18.609	-12.828	23.76	
03CADB0A67860801B35E82	22.5379	0.010898	-18.610	-12.828	23.79	
03CA3D0A67830801B25E8B	22.5536	0.010890	-18.627	-12.840	23.82	
03C8EC0A677E0801B35E9B	22.5872	0.010875	-18.613	-12.830	23.88	
03C7F90A677C0801B25E91	22.6114	0.010869	-18.628	-12.841	23.84	
03C63B0A677E0801B25E95	22.6559	0.010875	-18.628	-12.841	23.86	
03BFBA199F150803D05EAD	22.8227	5.011614	-10.095	-6.957	23.95	
03CA971987D70810225EEF	22.5447	4.969069	39.565	27.282	24.20	
04E0FB1806AB08437C5D5E	16.2108	4.286307	246.51	169.965	22.68	
0637351688F90883725798	9.9227	3.651432	504.146	347.599	17.07	
0778CA156B7F08CED05130	4.9768	3.203659	807.345	556.648	10.83	
07DF9415254B08F7984E66	3.5383	3.097099	971.188	669.613	8.11	
08281415013E094EEE4B2C	2.5580	3.042976	1321.399	911.075	4.97	

\* This test data set applies for both SBE 16plus V2 running its native firmware and the 16plus V2 running the 19plus V2 firmware.

Note that the conductivity data were calculated using the temperature (in degrees C) and pressure (in dbar), both of which were calculated from the original rawHex. See the TEMPWAT DPS (DCN 1341-00010) and PRESWAT DPS (1341-00020) for more details.

## Appendix A      Example Data Processing

Following are three examples, one for each CTD make/model. These are examples modified from the examples given in the CTD manuals.

### **SBE 16plus V2 with internally mounted strain gauge pressure sensor**

(OutputFormat = 0)

Hex scan = tttttccccpppppvvvvsssssss  
          = 0A53711BC7220C14C17D820EC4270B

- Temperature = ttttt = 0A5371 (676721 decimal);  
    temperature A/D counts = 676721
- Conductivity = 1BC722 (1820450 decimal);  
    conductivity frequency = 1820450 / 256 = 7111.133 Hz
- Internally mounted strain gauge pressure = pppppp = 0C14C1 (791745 decimal);  
    Strain gauge pressure A/D counts = 791745
- Internally mounted strain gauge temperature compensation = vvvv = 7D82 (32,130 decimal);  
    Strain gauge temperature = 32,130 / 13,107 = 2.4514 volts
- Time = ssssssss = 0EC4270B (247,736,075 decimal);  
    seconds since January 1, 2000 = 247,736,075

### **SBE 37IM with internally mounted strain gauge pressure sensor**

(OutputFormat = 0)

Hex scan = tttttccccppppTTTTTTTTT  
          = 531850c355e50a805F0C14

- Temperature: ttttt = 53185 hex = 340357 decimal  
    temperature (°C) = (ttttt / 10000) – 10 = (340357 / 10000) – 10 = 24.0357 °C
- Conductivity: ccccc = 0c355 hex = 50005 decimal  
    conductivity (S/m) = (ccccc / 100000) – 0.5 = (50005 / 100000) – 0.5 = 0.00005 S/m
- Pressure range: From file header (metadata for OOI), the pressure range is 1000 psia.  
    P\_range (dbar) = 0.6894757 \* [P\_range (psia) – 14.7] = 679.34040721
- Pressure: pppp = e50a in hex (bytes in reverse order) = 0ae5 in hex = 2789 decimal  
    pressure (dbar) = [pressure number \* P\_range / (0.85 \* 65536)] – (0.05 \* P\_range)  
                    = [2789 \* 679.34040721 / (0.85 \* 65536)] – (0.05 \* 679.34040721)  
                    = 0.045 dbar
- Time: TTTTTTTT = 805F0C14 hex (bytes in reverse order) = 140C5F80 = 336355200 decimal  
    seconds since January 1, 2000 = 336355200

## **Appendix B            Output Accuracy**

The algorithm output accuracy for the OOI L1 Conductivity core data product calculated by this algorithm is equivalent to the accuracy of the instrument:

SBE 16plus V2  $\pm 0.0005$  S/m with stability of  $\pm 0.0003$  S/m/month  
SBE 37IM  $\pm 0.0003$  S/m with stability of  $\pm 0.0003$  S/m/month  
SBE GPCTD  $\pm 0.0003$  S/m

The following requirements in the DOORS database describe conductivity accuracy requirements and are consistent with the accuracies stated above:

L2-SR-RQ-3471 Conductivity measurements shall have an accuracy of  $\pm 0.0003$  Siemens m-1 in the laboratory.

L2-SR-RQ-3835 Conductivity measurements shall have an accuracy of  $\pm 0.0003$  S/m for measurements taken at depths greater than 200m.

L2-SR-RQ-3836 Conductivity measurements shall have an accuracy of  $\pm 0.001$  S/m for measurements taken at depths less than or equal to 200m.

L2-SR-RQ-3837 Conductivity measurements shall have an accuracy of  $\pm 0.001$  S/m for measurements taken by AUVs and Gliders.

L2-SR-RQ-3473 Conductivity measurements shall have an annual drift of no more than 0.004 Siemens m-1.

Note that the accuracy requirements for the GPCTD, the CTD on the gliders and AUVs, are included here for completeness, but data from this make/model of instrument will be processed onboard the vehicles and presented already in decimal format in appropriate units ( $^{\circ}\text{C}$ , Siemens/meter, decibars). Therefore processing "raw" data from the CTDGP is not included in the algorithm described in this document.

## **Appendix C            Sensor Calibration Effects**

None.