OCEAN OBSERVATORIES INITIATIVE

DATA PRODUCT SPECIFICATION FOR PH OF SEAWATER

Version 1-00
Document Control Number 1341-00510
2012-08-20

Consortium for Ocean Leadership
1201 New York Ave NW, 4th Floor, Washington DC 20005
www.OceanLeadership.org

in Cooperation with

University of California, San Diego
University of Washington
Woods Hole Oceanographic Institution
Oregon State University
Scripps Institution of Oceanography
Rutgers University

Document Control Sheet

Version	Date	Description	Author
0-01	2012-05-03	Initial Draft	M. Neely
0-02	2012-05-10	L0 Updates	M. Neely
0-03	2012-05-11	MLankhorst updates	M.Lankhorst
0-04	2012-05-11	S Webster updates	S. Webster
0-05	2012-05-11	Combined updates for ML, SW, Orest Kawka	M. Neely
0-06	2012-07-20	Format updates.	S. Webster
0-07	2012-08-16	combined updates for MV,SW, and external reviewer A. Dickson (as annotated by SW)	M. Neely and S. Webster
1-00	2012-08-20	Initial Release	E. Chapman

Signature Page

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

OOI Senior Systems Engineer: ______________________

Date:2012-08-20

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

OOI CI Signing Authority: William ______________________

Date: 2012-08-20

Table of Contents

Appendix E Co-located CTD lookup tables for PHWATER data

1 Abstract

This document describes the computation used to calculate the OOI Level 1 pH of seawater core data product, which is calculated using data from the Sunburst SAMI-II pH instrument (PHSEN). This document is intended to be used by OOI programmers to construct appropriate processes to create the OOI Level 1 pH of seawater core data product.

2 Introduction

2.1 Author Contact Information

Please contact Merrie Beth Neely (mneely@oceanleadership.org) for more information, or the Data Product Specification lead (DPS@lists.oceanobservatories.org).

2.2 Metadata Information

2.2.1 Data Product Name

The OOI Core Data Product Name for this product is

- PHWATER

The OOI Core Data Product Descriptive Name for this product is

- pH of seawater

2.2.2 Data Product Abstract (for Metadata)

The OOI Level1 pH of seawater core data product is a measure of the acidity or basicity of a seawater sample on the total hydrogen ion scale (pH_T) used for CO_2 system calculations, nominally the concentration of hydrogen ions in seawater. However, pH is not precisely the concentration of hydrogen ions, but takes into account an activity factor. Hydrogen ion activity coefficients cannot be measured directly by any thermodynamically sound method, so they are based on theoretical calculations. The pH scale is defined in practice as traceable to a set of standard solutions whose pH is established by international agreement, but in the case of the Sunburst Sensor instrument and the measurement of seawater pH, Andrew Dickson's Tris CRMs are used to verify the accuracy before and after deployment; thus, the SAMI-pH measurements are directly traceable to the Dickson CRMs. The Tris CRM standards are accurate to ~0.002 pH units, but are only available at a single pH value and therefore validation over the entire pH operating range is not possible. The pH of seawater plays an important role in the ocean's carbon cycle. Ocean acidification caused by carbon dioxide emissions, can affect oceanic flora and fauna in many ways as well as biochemical and geochemical reactions.

2.2.3 Computation Name

Not required for data products.

2.2.4 Computation Abstract (for Metadata)

This computation computes the OOI Level 1 PH of seawater core data product, using data from the Sunburst SAMI-II pH instrument (PHSEN).

2.2.5 Instrument-Specific Metadata

See Section 4.4 for instrument-specific metadata fields that must be part of the output data.

2.2.6 Data Product Synonyms

Synonyms for this data product are

- pH of water
- pH

2.2.7 Similar Data Products

There are no similar data products. However, $p\mathrm{CO}_2$ measurements are related to pH in that both are used to describe the carbon chemistry of sea water.

2.3 Instruments

The Sunburst SAMI-II pH instrument was selected by the OOI to make this measurement on both mobile and fixed platforms. The instrument will have a copper intake tube to limit biofouling. On-board reagents and standards must be loaded prior to each deployment and must be within the manufacturer's expiration date (shelf-life) for proper operation. For information on the instrument from which the inputs to OOI Level 1 pH of seawater core data product are obtained, see the PHSEN Processing Flow document (DCN 1342-00510). This document contains information on the PHSEN instrument class make/model; it also describes the flow of data from the PHSEN instruments through all of the relevant QC, calibration, and data product computations and procedures.

Please see the Instrument Application in the SAF for specifics of instrument locations and platforms. This instrument will not be used on gliders or AUV's, but will be used on the RSN surface-piercing profiler/shallow profiler.

2.4 Literature and Reference Documents

[1] Direct observations of basin-wide acidification of the North Pacific Ocean, R. H. Byrne, S. Mecking, R. A. Feely, and X. Liu, Geophys. Res. Lett., 37, L02601, doi:10.1029/2009GL040999, 2010

[2] Byrne, R. H., Robertbaldo, G., Thompson, S. W. and Chen, C. T. A. (1988). Seawater pH Measurements - an at-Sea Comparison of Spectrophotometric and Potentiometric Methods. Deep-Sea Research Part a-Oceanographic Research Papers 35(8): 1405-1410.

[3] Clayton, T. D. and Byrne, R. H. (1993). Spectrophotometric Seawater pH Measurements - Total Hydrogen-Ion Concentration Scale Calibration of M-Cresol Purple and at-Sea Results. Deep-Sea Research Part I-Oceanographic Research Papers 40(10): 2115-2129.

Liu, X., M.C. Patsavas, R.H. Byrne. 2011. Purification and Characterization of meta-Cresol Purple for Spectrophotometric Seawater pH Measurements. Environmental Science and Technology. 45:4862-4868.

OPERATING MANUAL AFT/SAMI^2-pH, Sunburst Sensors LLC, (Version unknown but circa February 2012)

Martz, T.R., Carr, J.J., French, C.R., DeGrandpre, M.D., 2003. A submersible autonomous sensor for spectrophotometric pH measurements of natural waters. Anal. Chem, *75*, 1844-1850

Seidel, M.P., DeGrandpre, M.D., Dickson, A.G., 2008. A sensor for *in situ* indictor-based measurements of seawater pH. Mar Chem. 109, 18-28.

See also anything posted on:
https://confluence.oceanobservatories.org/display/science/Common+Instrument+ICD
https://confluence.oceanobservatories.org/display/Presentations/OOI+PHSEN+Collaboration

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).

concentration - is a measure of the amount of something in something else, in this case the amount of hydrogen ions per kg of solution.

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). The following acronyms and abbreviations are defined here for use throughout this document.

COTS – commercial off the shelf
DI – Deionized water
mCP - meta-Cresol Purple
LED – light emitting diode
TB - thymol blue
Tris – tris(hydroxymethyl)aminomethane, with the formula $(HOCH_2)_3CNH_2$
SAMI = Submersible Autonomous Moored Instrument, specifically the Sunburst AFT/SAMI-II-pH

2.5.3 Variables and Symbols

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

ε - molar absorptivities
K'_a – dissociation constant
pK'_a – negative log of the dissociation constant
e_1, e_2 and e_3 – salinity and temperature-dependent ratios of the molar absorptivities (ε) of HI^- and I^{2-} at 434 and 578 nm determined at the factory and provided by the vendor in the firmware
R - absorbance ratio A578/A434
I – a measure of the light intensity transmitted through a seawater and indicator mixture
I_0 – a measure of the light intensity transmitted through a pure seawater solution (blank)
A – absorbance at each wavelength

3 Theory

3.1 Description

The Sunburst Sensor Sami II pH instrument allows the user to measure seawater pH on the total scale (pH_T) using a colorimetric reaction occurring in an indicator solution. A seawater sample stream is pumped through the instrument and injected with a pH-dependent indicator solution. Two wavelength-specific LEDs send alternating pulses of light through the indicator-sample mixture as it is pumped through a flow cell. The ratio of the absorbance at the two wavelengths with and without the dye, Beer's law, and the molar absorptivities of the indicator can be used to calculate the concentration of protonated and un-protonated indicator. The indicator pK'a is then used to calculate pH. pH_T measures the ratio of indicator dye in a seawater sample and infers the activity of both protons (free hydrogen ions) and hydrogen sulfate ions in the colorimetric reaction. It is the preferred method for evaluating CO_2 measurements in seawater. The alternatives are the free scale (pH_F), which ignores hydrogen sulfate ions and can only be considered an estimate, and the seawater scale (pH_{SWS}), which further accounts for protonation interactions between hydrogen and fluoride ions.

Optical Path
The SAMI uses pulsed LEDs with narrow band filters at wavelengths corresponding to maximum optical absorbance for the protonated and deprotonated forms of the reagent. A reference photodiode tracks changes in the light sources. Light is transmitted to and from the flow-cell via 800-µm optical fibers. In the SAMI-pH **the flow-cell optical path length is 1 cm**.

Fluid Path
The SAMI- pH uses a 50 µl solenoid pump to drive reagent through the system. A solenoid valve allows the same pump to introduce a single pulse of reagent into the stream for each pH measurement. A 350-µl static mixer upstream of the flow cell ensures thorough mixing of the sample and reagent prior to optical measurements. The sample's blank signal intensity (I_0) is established by taking measurements while pumping pure sample through the flow cell. After measuring the blank signal, reagent is introduced into the flow stream and light intensity (I) is collected as the pump pushes the mixture through the flow-cell. Optical blanks are required so that accurate indicator absorbance ratios (R) can be calculated.

3.2 Mathematical Theory

Equilibrium Reaction
Spectrophotometric pH determination is based on the equilibrium reaction of a pH-dependent indicator. A diprotic sulfonephthalein indicator, meta-Cresol Purple (mCP), is used as the reagent. A single 50-µL pulse of reagent is introduced into the seawater stream. The ratio of the acidic (HI^-) and basic (I^{2-}) forms of the indicator varies based on the pH of the seawater being tested.

Indicator equilibrium is described by Equation 1: $HI^- \xleftrightarrow{K_a'} I^{2-} + H^+$

where K'a and pK'a are the apparent dissociation constant and the negative logarithm of the apparent dissociation, respectively. The acidic and basic forms of the indicator are measured at peak absorbance wavelengths of 434 nm (HI^-) and 578 nm (I^{2-}). The diprotic H_2I form is not present at seawater pH and therefore is not considered in our applications.

Combining the log form of the indicator equilibrium expression and Beer's Law results in

Equation 2: $pH = pK'a + \log\ [(R-e_1)/(e_2-Re_3)]$

where R is the absorbance ratio A578/A434, A578 refers to the absorbance at the wavelength 578 nm and A434 refers to the absorbance at the wavelength 434 nm, and the e_i are the salinity and temperature-dependent ratios of the molar absorptivities (ε) of HI^- and I^{2-} at 434 and 578 nm.

The absorbance at each wavelength is calculated as:

Equations 3: $A = -\log (I/I_0)$

where I is a proportional (not actual) measure of the intensity of light transmitted through a seawater and indicator mixture and I_0 is a proportional (not actual) measure of the intensity of light transmitted through pure seawater (the blank).

3.3 Known Theoretical Limitations

Algorithm results are only valid between 0 – 35 °C and at 35(+/-1) salinity. The algorithm default assumes a salinity of 35 and does not appreciably affect pH accuracy if salinities are +/ 1, however, when salinities drop below 34 or go above 36, a correction can be applied through data post-processing using salinity data from a nearby instrument. Alternatively, if the PHSEN instrument is connected to a SeaBird CTD a subroutine can be programmed into the driver to replace the default of 35 with the most recent salinity value from the CTD in the equation. **The code for this subroutine is available from Sunburst upon request.**

It is known impurities exist in the TB and mCP commercially available today from all vendors. The impurities lead to variations in light absorbance, affecting the calculations of molar absorptivities and thereby pH (Liu et al, 2011, among other authors). This type of error will be minimized through the removal of impurities in new reagent batches and also through algorithm adjustments reflected in future software upgrades, and validated at water sample temperatures down to 5˚C (Liu et al, 2011). Both reagents and software upgrades are planned for release in late 2012, at which time this DPS will need revised. It is also known characteristics of the dye change with pressure, but the effects are not yet well understood. This is currently not accounted for in the calculation of pH presented here.

Acknowledgment of the State of the pH Sensor by OOI Scientists
Measurements of oceanic pH on the low end of the range specified in the OOI requirements (7.3 to 8.5) are not uncommon today ([1]) in the N Pacific Ocean (see Figures 1 and 2, methodologies may differ). The precision of spectrophotometric pH measurements depends greatly on the selection of a suitable indicator, which in turns depends primarily on the anticipated pH of the sample. The commonly used indicator m-Cresol Purple (mCP) has an optimal range of 7.1 – 8.1. But for surface ocean, pH is often greater than 8.1 (ca. 8.6 in highly productive plume water), which is out of the optimal range of mCP. In this case, thymol blue (TB), with an optimal range of 7.6-8.6, is often used as the indicator for surface samples. For the oceanic pH range (7.3 – 8.5, as requested by the OOI), there is **no single indicator** that will cover this measurement range with optimal performance. The scientists acknowledge that the commercial off the shelf (COTS) pH sensors, including those considered to be ‘the best in the business’ and used worldwide, are only designed to carry one indicator (mCP, TB, or other indicator), and thus cannot achieve the optimal measurement performance for the entire oceanic pH range that may be encountered(2,3). Measurements made on the high or low end may be less precise, due to limitations of either chemical indicator. The precision and accuracy of pH measurements are most important in surface waters, where greater variability between measurements is likely to be found. However, surface waters generally have higher pH. The lowest pH waters are usually found in the stable deeper layers below 500-600 meters in open ocean, and these values are typically more stable temporally. The scientists also acknowledge that the current COTS sensor the OOI purchases may be the best available sensor, yet still not meet every threshold performance requirement in the pH sensor specification for fixed platforms and suffer from the single-indicator limitation.

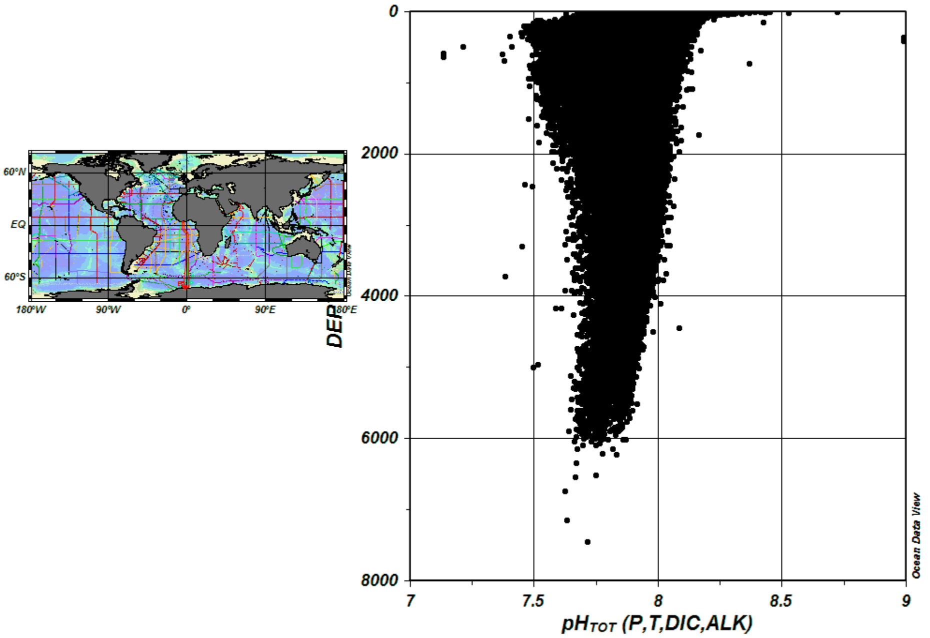

Figure 1. Global distribution of pH values measured in situ. Seawater pH values below 7.5 are limited in number, however there will be instances that OOI sensors will encounter these conditions (e.g. in the North Pacific- Station PAPA and RSN) – source G. Proskurowski and RSN contractor.

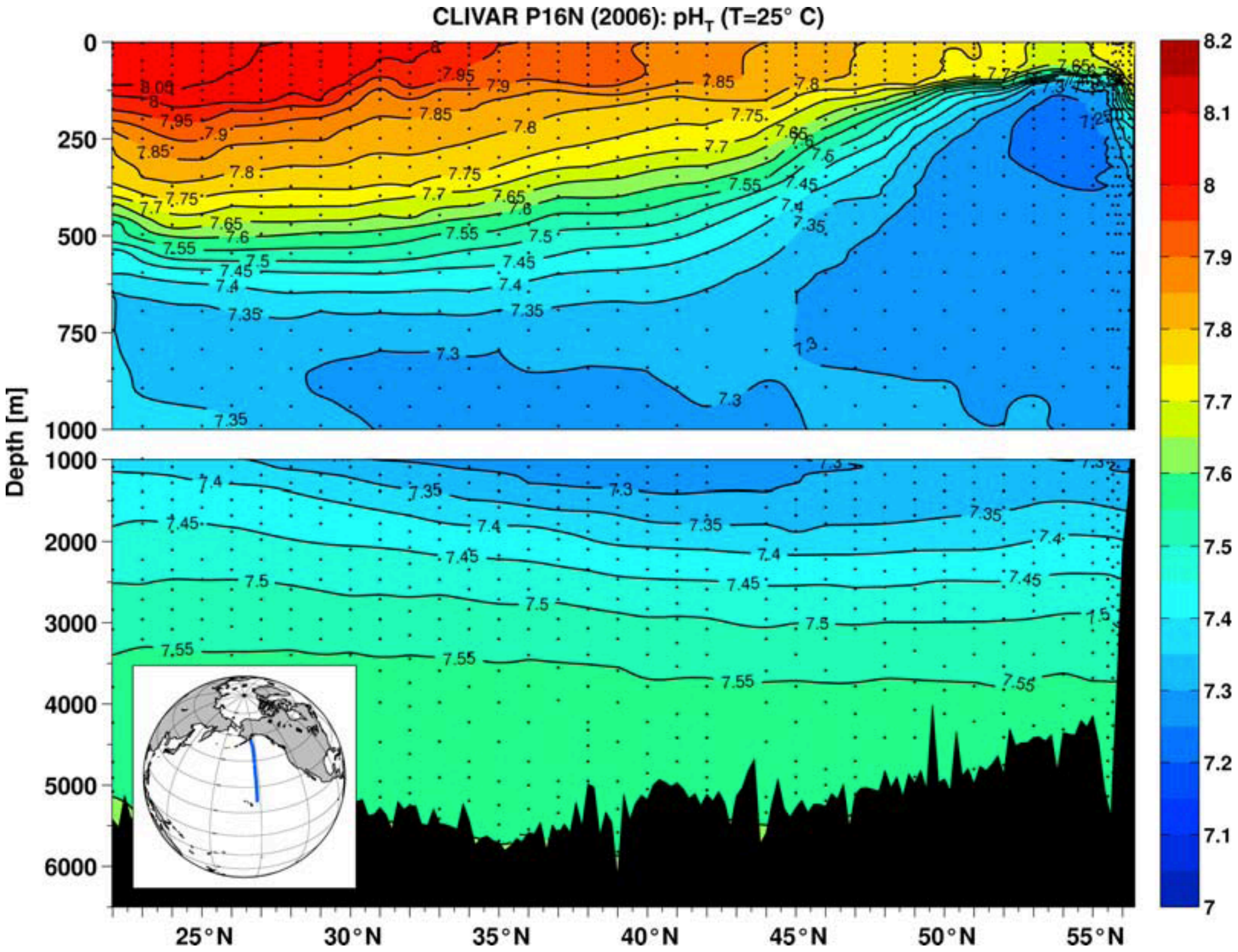

Figure 2. North Pacific Ocean pH along 152_W in 2006 (pHT, 25_C). Reprinted from Byrne et al 2010.

Figure 2. Northeast Pacific Ocean pH by depth and latitude (from Byrne et al, 2010).

3.4 Revision History

No revisions to date.

4 Implementation

4.1 Overview

The conversion from L0 to the L1 pH of seawater data product is implemented using the Equation 2 in Section 3.2 and the code provided in Appendix A.

4.2 Inputs

Level 0 signal intensity data from the PHSEN instrument represent A (absorbance) at each wavelength needed for the L1 data equation (434 and 578 nm). L0 PH434SI is the intensity measurement of the wavelength 434nm and L0 PH578SI is the intensity measurement of the wavelength 578nm. Signal intensities can range from 0 to 4096 (unitless).

L0 ABSTHRM is the thermistor resistivity, which is needed to determine the salinity and temperature-dependent molar absorptivities required for the pH calculation.

Inputs are:

- L0 PH434SI signal intensity at 434nm ranging from 0 to 4096 (corresponds to a direct current volt range of 0 to 5).
- L0 PH578SI signal intensity at 578nm ranging from 0 to 4096 (corresponds to a direct current volt range of 0 to 5).
- L0 ABSTHRM thermistor resistivity with a DC volt range of 0 to 5.
- Wavelengths used to evaluate pH blank and sample absorptivities. These are set by the instrument firmware and are 434 nm and 578 nm for all OOI PHSEN instruments. These two wavelengths should be stored as metadata.
- ei - salinity and temperature-dependent ratios of the mCP molar absorptivities. These values are based upon test results of the reagent batches supplied by the vendor and are pre-loaded onto the instrument firmware. These differ between reagent batches and should be stored as metadata
- Preset constant 35 salinity unless using Additional input from attached CTD*.

*Additional optional input if PHSEN instrument is attached to a SeaBird CTD:

- L2 PRACSAL practical salinity based on the most recent measurements from an attached CTD. See Appendix E for a list of the reference designators for all pH instruments for which this applies.

Input Data Format

Raw Record Structure

There are 2 main types of records recorded by the instrument: data records and information records. Information records note events such as ‘start’, ‘stop’, ‘battery low’ and possible errors.

Computed fields

The three L0 data values used to calculate the pH of seawater data product are contained in a floating decimal string as described below. Computed fields consist of data derived from the raw records. If the user wants to log data externally, the client software has the capability of reading text files with the logged hex strings described below. The only requirement is that each record is written to a separate line in the file.

Following the identifiers, all records begin with a byte containing length count. The length count includes the length and checksum bytes. A record can be up to 255 bytes long. The second byte is record type. The next 4 bytes are the time, seconds since Jan 1, 1904 GMT (total seconds).

Example:

This string is the beginning of a SAMI-pH record sent over the serial port:

*BFE70AC8EF9AF8...

The '*' indicates a record is to follow. The 'BF' represents a hash of the SAMI name and the stored validation values (a unique identifier). 'E7' is hexadecimal for 231 and is the length of the record. '0A' (10 decimal) indicates this is a pH record. 'C8EF9648' is the date/time in seconds and translates to October 28, 2010 21:26 GMT.

All records end with a 1 byte checksum - the low byte of the sum of the bytes including the length and type. This is used for error checking of the transmission.

SAMI-pH Data Records

Bytes	Description
1	Length
1	Type
4	Time
2	Starting thermistor
32	16 sets of reference light measurements (2 bytes ea.)
184	23 sets of 4 light measurements (2 bytes ea.)
2	(not used currently)
2	Battery
2	Thermistor
1	Checksum

On-board reference standard(s) (a.k.a. On-board Tris accuracy system) can be used to periodically update relative absorbance, as invoked by a marine operator or at pre-determined intervals recommended by the vendor (every 4-5 days is recommended), but frequency of this test would depend upon deployment length and sampling frequency. This test report does not rebaseline the instrument but appears as a separate metadata stream with a different data type (for the Sunburst SAMI-II it is data type 11 as opposed to data type 10 which is used for routine samples).

Range checks on the inputs are as part of the global range check (GLBLRNG, DCN 1341-10004) specified in the PHSEN Processing Flow documents (DCN 1342-00510). A separate range check on the inputs does not need to be applied.

The sample processing interval must be offset at no less than 4 minutes for the colorimetric reaction to occur (which takes 2.1 minutes after the period of pumping to gather the sample and perform the blank) and to account for pump timing (which can only be set in whole number minutes, not fractions).

4.3 Processing Flow

The specific steps necessary to create all calibrated and quality controlled data products for each OOI core instrument are described in the instrument-specific Processing Flow documents (DCN 1342-XXXXX). These processing flow documents contain flow diagrams detailing all of the specific procedures (data product and QC) necessary to compute all levels of data products from the instrument and the order in which these procedures are to be applied.

The processing flow for the pH of seawater computation is as follows:

Step 1:
The instrument-specific information must be captured from the most-recent factory calibration sheet. The marine operator must perform the field/shipboard determination of blank and reference standard procedure using the on-board blanks and standards (a.k.a. On-board Tris accuracy system). The information from field/shipboard calibration is saved as instrument metadata to be provided to CI immediately post-deployment to 'update' the automated pre-deployment (L1b) data QC equations applied to the real-time data. The instrument can then be deployed.

Step 2:
The conversion of absorbance (L0 PH578SI and L0 PH434SI) and salinity/temperature (L0 ABSTHERM) from the instrument to pH of seawater data product (L1 PHWATER) is straightforward using the equation:

$$\mathrm{pH} = \mathrm{pK'a} + \log\ [(R-e_1)/(e_2-Re_3)]$$

The pKa´ is the indicator salinity and temperature-dependent equilibrium constant, R is the absorbance ratio A578/A434 corresponding to the peak absorbances of the unprotonated and protonated forms of the indicator (in this case mCP). The ei are the salinity and temperature-dependent ratios of the mCP molar absorptivities available from the vendor and preset in the firmware.

Step 3:
The appropriate automated QC tests are global range, spike, stuck value, local range, and temporal spatial gradient tests may be applied. However, the nature of local pH conditions make it difficult to set the parameters for all these tests with certainty at first deployment. Data should better inform these parameter limits on a location-specific and depth-specific basis.

4.4 Outputs

The output of the pH of seawater computation is

- L1a pH of seawater (unitless) as a decimal floating point number %.
- .

The OOI Level 2 science program requirement for accuracy is +/-0.01, precision is +/- 0.005, and drift of not more than 0.01 of pH of seawater.

The metadata that must be included with the output are

- Time
- Temperature in degrees C
- Salinity (either as default of 35 or as reported by the attached SeaBird CTD)
- Reference standard and blank absorbances used in this calculation during field/shipboard calibration
- Any corresponding post-deployment or at-recovery field pH *in situ* measurements, or post-recovery drift corrections determined at the time of annual factory service used to refine the above field calibration factor for L1b or L1c data.

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

There are no computational limitations or requirements.

4.6 Code Verification and Test Data Set

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 output.

Test Data Input:

```
*A3E70ACAB31FBB05B007DD066A074708A607E00669074B08A207E20669074B08A207E206
67074D0
8A307E5066B074D08A407E2066B074C08A307E2065F0749088D07DB05EB0745076307E304
7A074D0
45F07E302C6074801EE07DF01B8074700EB07DB014C074600A307E101400748009E07E0017
307470
0C107E101CD074A010307E002530746017807E202EA074C021507E30383074B02D507E2041
2074C0
3AF07E104910748048107E204F0074F053907DE0540074905DF07DF05820746066807E205A
F07490
6D207DF05D90746072F07E105F00745076A07E40609074C07A500000C4405B013

*A3E70ACAB349EB05B507E40668075408AA07DE0667075208AB07DD066A075108AD07E206
6907540
8AD07DF066B075308B007DC0667074E08A907E206600750089207DD05EB074F075707DF04
6C07540
42A07E302CB075301D407E001C3075000E207E3015C074E009907E2014A074C009007DF01
7C07510
0B007E201DC075000FB07DF02650752016E07E203000751021307DF0395075102D407E1041
F07510
3A507E3049A0752047907E304F9074E053207DD054C075205DF07DD05820751066507E005B
407510
6CF07E705DF0754072F07E105F60751077507DF060B075107AC00000C4305B671

*A3E70ACAB3741B05B807DE0666075408AE07E00668075408AD07DF0668075808B007DE06
6B07530
8B207E4066A075208B007E0066B075408B107E206600759089407DF05E40751073C07E0047
707570
41407E102E0075201C307DD01DE074F00D807DF016F0756008E07E3015E0755008507DA01
8F07550
0A707DF01E8075300E707E6026F0754015207DF02FF075201E707DF0393075102A507DE041
F07510
37907DF049B0752045207DD04F80756051007E10548075405BB07DE05860752065007E305B
207510
6C407E605D90754072007DC05F2074F076307DF060B075407A400000C4305B8B5

*A3E70ACAB39E4B05BC07DF0668075A08B907E00668075A08B507DF0668075808B607E206
67075A0
8B807DE0668075B08B507DE0665075A08B407E00661075A089D07E205E9075A075807DE04
```

```
8B07580
44707DC02FC075901E807DE01E6075900E207E80174075C009707DE01630758008C07E1018
D07570
0A607DC01E9075600E807E10264075A014C07DE02FC075701EC07E10391075802A907E104
2107570
38007DF04910758044B07E304F50757051207E40547075805C007E0057F0757064807E005B0
07570
6BD07E705D5075C071C07E105F2075C076B07E00608075B07A400000C4205BC88

*A3E70ACAB3C87B05BA07D90666075908B407DF0664075B08B207DD0666075708B407E106
6607560
8B607DE0668075A08B707DF0669075808B607DF065E0759089907DE05E8075C074707DF04
76075A0
41007DF02D3075501AF07E401D5075D00CB07E3016C0756008A07E0015F0757008107E0019
107580
0A307E301FA075C00EA07E6027D075A015907DF030C075701F107DD03A3075802B307DD04
2D07560
38607DF04A30757045C07DF04FD0756051A07E0054E075C05C707E1058B075C065507DD05
B607560
6C807E005DA0756072307DF05F20757076907E0060D075807AB00000C4205BA99

*A3E70ACAB3F2AB05B207E00669075108AF07DD0663075308AB07E40666075208AB07DB06
6807510
8A907DC0663074C08AA07DE0666075008AF07DF065C0751088F07DF05E30753073B07DF04
8A074C0
43807DE02F3074D01D707DC01DF074E00D807DD016F0752008E07DC0160074F008807DE0
18B074C0
0A107E301E7075400DF07DE025C0750014507DD02F1074F01D607D903870749029307DC04
1107510
36007E004920753044307DA04EE074B04FC07DC0543074C05B107DC05810749064707DC05
B0074C0
6B207DE05D4074F071507DF05EE0750075C07DF06070751079900000C4105B20D
```

Test Data Output:

Type	**Time**	**Batt (Volts)**	**TempFinal (˚C)**	**FinalpH**
10.0000	3400704299.0000	11.5100	25.8275	8.0718
10.0000	3400715099.0000	11.5063	25.8341	8.0493
10.0000	3400725899.0000	11.5063	25.8717	8.0185
10.0000	3400736699.0000	11.4990	25.8839	8.0082
10.0000	3400747499.0000	11.4954	25.8620	8.0250
10.0000	3400758299.0000	11.4954	25.8364	8.0540
10.0000	3400769099.0000	11.4917	25.8029	8.0520
10.0000	3400779899.0000	11.4917	25.7845	8.0628
10.0000	3400790699.0000	11.4880	25.7937	8.0565

Appendix A Example Code

Matlab Code example below was provided by the vendor Sunburst Sensors LLC. It captures all of the DPS steps above and reflects the software the Sunburst-SAMI instrument currently uses. One external reviewer questioned the use of the steps noted below and the vendor's recommendation is included for posterity.

Notes specific to section of this example matlab code:

% Average Temperature: The SAMI takes a temperature measurement at the beginning of the sample (prior to flushing) and there's another temperature measurement at the end of the measurement cycle. The entire sample takes ~3 minutes but the actual pH measurement is done during the last 46 seconds. Sunburst's recommendation for OOI coders is to just use the 2nd temperature measurement for the calculation of R instead of the average temperature step captured here in this code.

% pKa from Clayton/Byrne 1993: This is the pK′a calculation that will change slightly in the late 2012 software upgrade. Updated example matlab code to reflect the changes will be included in a revised PHWATER DPS when this occurs. Sunburst is using dye purification methods described in Lui et al (2011), however, the equations may differ slightly because the molar absorptivities must be known for this instrument in order to calculate the indicator concentration that is needed to extrapolate to zero indicator.

% Determine the most linear region of points for seawater calculation
% Skip first 5 points: This code selects the most linear region of measurement points dynamically instead of using a set of static points from the SAMI instrument. This is necessary because if there is significant biofouling or a partial block at the sample inlet port, the points in the curve will shift due to the lower flow rate. The example code provided uses the best 7 points by using a moving filter to find the best R^2. Sunburst strongly recommends OOI implements an identical step in the code.

```
%  ************************************************************************
% SAMI2-pH Telemetry Program
% This m-file will read in raw data hex strings that are output from the
% SAMI2-pH instrument and process and output:
%   - Time
%   - pH
%   - Temperature
% ***************************************************************************
clear all
% Constants
cp = 1; % cell path length
% Molar absorptivities - unique to indicator lot
ea434=17709;
ea578=107;
eb434=2287;
eb578=38913;
eaTemp=24.8000;
ebTemp=24.8600;
Inta434 = ea434 + 24.5250*eaTemp;
Inta578 = ea578 - 0.5869*eaTemp;
Intb434 = eb434 - 6.2231*ebTemp;
Intb578 = eb578 + 99.6170*ebTemp;
Salinity=35;
% ***************************************************************************
% Select the SAMI-pH file to analyze
```

```
[File,myPath]=uigetfile('*.*','Select the file to analyze');
cd(myPath);
fid = fopen(File);

% Path name for saving output files
fname=[myPath,File];
outfile=strcat(fname(1:end-4),'_out1.txt'); % path for saving data files

% ****************** Read in hex data from SAMI2-pH ********************
% Search for start string of data '*----0A' where - is any hex char.
% Fgetl returns -1 on EOF to end loop.
i=1; j=1;
while 1
s=fgetl(fid);
if s == -1, break,end  % indicates EOF
   if (strcmpi('*',s(1:1))==1 && strcmpi('0A',s(6:7)))
      s = s(2:length(s));
      while length(s)<464
         s = [s,fgetl(fid)];
      end
      AA(i,:)= s;
      i=i+1;
   else
   end
end
fclose(fid);
[s1,s2]=size(AA);
% ************************************************************************
% Extract data from hex string
for i=1:s1
   Type(i)=hex2dec(AA(i,5:6)); % Type 10 - measurement
   % Date/Time
   Time(i)=hex2dec(AA(i,7:14));
   dt(i)=(Time(i)/(60*60*24));
   [y(i) m(i) d(i) h(i) mn(i) s(i)]=datevec(dt(i));
   y2(i)=y(i)+1904;
   Date(i,:)=datestr(datenum([y2(i) m(i) d(i) h(i) mn(i) s(i)]), 'mmmm dd, yyyy HH:MM:SS');
   datetime1(i)=(Time(i)/(60*60*24));

   Temp1(i)=hex2dec(AA(i,15:18));   % Temp taken at beginning of measurement
   chksum=hex2dec(AA(i,463:464));   % Checksum
   Temp2(i)=hex2dec(AA(i,459:462)); % Temp taken at end of measurement
   Batt(i)=hex2dec(AA(i,455:458));  % Battery voltage

   % Raw blank measurements (4 total)
   Ref434A(i,:)=hex2dec(AA(i,19:22));
   Sig434A(i,:)=hex2dec(AA(i,23:26));
   Ref578A(i,:)=hex2dec(AA(i,27:30));
   Sig578A(i,:)=hex2dec(AA(i,31:34));

   Ref434B(i,:)=hex2dec(AA(i,35:38));
   Sig434B(i,:)=hex2dec(AA(i,39:42));
   Ref578B(i,:)=hex2dec(AA(i,43:46));
   Sig578B(i,:)=hex2dec(AA(i,47:50));

   Ref434C(i,:)=hex2dec(AA(i,51:54));
```

```
    Sig434C(i,:)=hex2dec(AA(i,55:58));
    Ref578C(i,:)=hex2dec(AA(i,59:62));
    Sig578C(i,:)=hex2dec(AA(i,63:66));

    Ref434D(i,:)=hex2dec(AA(i,67:70));
    Sig434D(i,:)=hex2dec(AA(i,71:74));
    Ref578D(i,:)=hex2dec(AA(i,75:78));
    Sig578D(i,:)=hex2dec(AA(i,79:82));

    % Blank absorbances
    Blank434A(i,:)=Sig434A(i,:)/Ref434A(i,:);
    Blank578A(i,:)=Sig578A(i,:)/Ref578A(i,:);
    Blank434B(i,:)=Sig434B(i,:)/Ref434B(i,:);
    Blank578B(i,:)=Sig578B(i,:)/Ref578B(i,:);
    Blank434C(i,:)=Sig434C(i,:)/Ref434C(i,:);
    Blank578C(i,:)=Sig578C(i,:)/Ref578C(i,:);
    Blank434D(i,:)=Sig434D(i,:)/Ref434D(i,:);
    Blank578D(i,:)=Sig578D(i,:)/Ref578D(i,:);
    % Average blank absorbance
    blank434(i,:)=(Blank434A(i,:)+Blank434B(i,:)+Blank434C(i,:)+Blank434D(i,:))/4;
    blank578(i,:)=(Blank578A(i,:)+Blank578B(i,:)+Blank578C(i,:)+Blank578D(i,:))/4;

% Reference and signal measurement raw intensities
    j=1;
    for ii=83:16:s2-30
        Ref434(i,j)=hex2dec(AA(i,ii:ii+3));
        I434(i,j)=hex2dec(AA(i,ii+4:ii+7));
        Ref578(i,j)=hex2dec(AA(i,ii+8:ii+11));
        I578(i,j)=hex2dec(AA(i,ii+12:ii+15));
        j=j+1;
    end
    % Thermistor calculations
    Rt1(i)=(Temp1(i)/(4096-Temp1(i)))*17400;
    InvT1(i)=0.0010183+0.000241*(log(Rt1(i)))+0.00000015*(log(Rt1(i)))^3;
    TempK1(i)=1/InvT1(i);
    TempC1(i)=TempK1(i)-273.15;
    TempF1(i)=1.8*TempC1(i)+32;
    TempFinal1(i)=TempC1(i);

    Rt2(i)=(Temp2(i)/(4096-Temp2(i)))*17400;
    InvT2(i)=0.0010183+0.000241*(log(Rt2(i)))+0.00000015*(log(Rt2(i)))^3;
    TempK2(i)=1/InvT2(i);
    TempC2(i)=TempK2(i)-273.15;
    TempF2(i)=1.8*TempC2(i)+32;
    T(i)=(TempC1(i)+TempC2(i))/2;
    % Average Temperature
    TempFinal(i)=mean(T);
end

Ref434=Ref434'; I434=I434'; I578=I578';Ref578=Ref578';
[d3,d4]=size(I434);
for j=1:d4
    % Absorbances
    A434(:,j) = -log10(I434(:,j)./Ref434(:,j) );
    A578(:,j)  = -log10(I578(:,j)./Ref578(:,j) );
```

```
    A434blank(1:d3,j)=-log10(blank434(j));
    A578blank(1:d3,j)=-log10(blank578(j));

    Abs434(:,j) =A434(:,j)-A434blank(:,j) ;
    Abs578(:,j) =A578(:,j)-A578blank(:,j) ;

    % pKa from Clayton/Byrne 1993
    pKa(1:d3,j)=(1245.69./(TempFinal(j)+273.15))+3.8275+(0.0021*(35-Salinity));
    R(:,j) = (A578(:,j)-A578blank(:,j))./(A434(:,j)-A434blank(:,j));

    % Molar absorptivities
    Ea434(1:d3,j) = -24.525*TempFinal(j) + Inta434;
    Ea578(1:d3,j) = 0.5869*TempFinal(j) + Inta578;
    Eb434(1:d3,j) = 6.2231*TempFinal(j) + Intb434;
    Eb578(1:d3,j) = -99.617*TempFinal(j) + Intb578;

    e1(:,j) =Ea578(:,j)./Ea434(:,j);
    e2(:,j) =Eb578(:,j)./Ea434(:,j);
    e3(:,j) =Eb434(:,j)./Ea434(:,j);

    V1(:,j)=R(:,j)-e1(:,j);
    V2(:,j)=e2(:,j)-R(:,j).*e3(:,j) ;

    % Indicator concentration calculations
    HI(:,j)=((Abs434(:,j).*Eb578(:,j))-(Abs578(:,j).*Eb434(:,j)))./((Ea434(:,j).*Eb578(:,j))-
(Eb434(:,j).*Ea578(:,j)));
    I(:,j)=((Abs578(:,j).*Ea434(:,j))-(Abs434(:,j).*Ea578(:,j)))./((Ea434(:,j).*Eb578(:,j))-
(Eb434(:,j).*Ea578(:,j)));

    % Use data points that are in linear region
    IndConc(:,j)=HI(:,j)+I(:,j);
    pointpH(:,j)=real(pKa(:,j)+log10(V1(:,j)./V2(:,j)));

  % ********************************************************************
  % Determine the most linear region of points for seawater calculation
  % Skip first 5 points
  IndConca(:,j)=IndConc(6:d3,j);
  Y(:,j)=pointpH(6:d3,j);
  X=[1:1:d3-5]';

  step=7; % # of pts to use
  count=step+1;
  for ii=1:length(X)-step
      sumxa(ii,j)=sum(X(ii:ii+step));
      sumya(ii,j)=sum(Y(ii:ii+step,j));
      sumxya(ii,j)=sum(X(ii:ii+step).*Y(ii:ii+step,j));
      sumx2a(ii,j)=sum(X(ii:ii+step).^2);
      sumy2a(ii,j)=sum(Y(ii:ii+step,j).^2);
      avgxa(ii,j)=mean(X(ii:ii+step));
      avgya(ii,j)=mean(Y(ii:ii+step,j));

      sumxx2a(ii,j)=sumxa(ii,j).*sumxa(ii,j);
      sumyy2a(ii,j)=sumya(ii,j).*sumya(ii,j);
      ssxya(ii,j)=sumxya(ii,j)-(sumxa(ii,j).*sumya(ii,j))/count;
      ssxa(ii,j)=sumx2a(ii,j)-(sumxx2a(ii,j)/count);
      ssya(ii,j)=sumy2a(ii,j)-(sumyy2a(ii,j)/count);
```

```
      slopea(ii,j)=ssxya(ii,j)./ssxa(ii,j);
      r2a(ii,j)=((ssxya(ii,j).^2)./(ssxa(ii,j).*ssya(ii,j)));
  end

  % Range of seawater points to use
  [xia,yia]=max(r2a(:,j));  % Find start point of the best fit using best R-squared
  cutoff1(j)=yia;           % Start point
  cutoff2(j)=yia+step;      % End point

  IndConcS(:,j)=IndConca(cutoff1(j):cutoff2(j),j);
  pointpHS(:,j)=real(Y(cutoff1(j):cutoff2(j),j));
  [a1(j) a2(j)]=size(pointpHS);

% ************************* Final pH Calcs ********************************
   sumx(1,j)=sum(IndConcS(:,j));
   sumy(1,j)=sum(pointpHS(:,j));
   sumxy(1,j)=sum((pointpHS(:,j).*IndConcS(:,j)));
   sumx2(1,j)=sum((IndConcS(:,j).^2));
   sumy2(1,j)=sum((pointpHS(:,j).^2));

   xbar(1,j)=mean(IndConcS(:,j));
   ybar(1,j)=mean(pointpHS(:,j));

   sumxx2(:,j)=sumx(1,j).*sumx(1,j);
   sumyy2(:,j)=sumy(1,j).*sumy(1,j);
   ssxy(1,j)=sumxy(1,j)-(sumx(:,j)*sumy(:,j))/a1(j);
   ssx(1,j)=sumx2(1,j)-(sumxx2(:,j)/a1(j));
   ssy(1,j)=sumy2(1,j)-(sumyy2(:,j)/a1(j));
   slope(1,j)=ssxy(1,j)./ssx(1,j);
   FinalpH(1,j)=ybar(1,j)-(slope(1,j).*xbar(1,j));
end
% ******************** Figures *****************************
X2=[1:1:d3];
X2=X2';
    % Plot of reference and signal channels
    figure
    subplot(2,1,1);
    plot(X2,Ref434,'-bo',X2,Ref578,'-ro')
    title('Reference Signals');ylabel('Reference')
    grid on, axis tight
    subplot(2,1,2);
    plot(X2,I434,'.b',X2,I578,'.r')
    title('Intensity Signals');ylabel('Signals')
    grid on, axis tight

    % Plot of seawater point pH
    figure
    plot(real(pointpH),'.-')
    title('Sea Point pH');ylabel('pH')
    grid on, axis tight
    ylim([7 9])

    x1=[1:1:length(FinalpH)];
    % Plot of Seawater Final pH
    figure
    [AX,H1,H2]=plotyy(x1,FinalpH,x1,TempFinal);
```

```
    set(get(AX(1),'Ylabel'),'String','Final Sea pH')
    set(get(AX(2),'Ylabel'),'String','Temp (C)')
    set(H1,'LineStyle','-.','marker','.')
    set(H2,'LineStyle','-.','marker','.')
    grid on
% ****************************************************************************
% Output file
fid = fopen(outfile,'w');
fprintf(fid,'Time \t TempFinal \t FinalpH \t \r\n');
fmt = '%8.4f \t %8.4f \t %8.4f \t  \r\n';
data=[Time; TempFinal; FinalpH];
fprintf(fid,fmt,data);
fclose(fid);
```

Appendix B Output Accuracy

The DOORS accuracy requirement for pH is +/-0.01 units and the objective is to have accuracy of +/-0.005 units. The statement of accuracy by the manufacturer is +/-0.003 units.

Appendix C Sensor Calibration Effects

This instrument must be calibrated at expected *in situ* temperatures and to the appropriate standard (mCP or TB) for reading expected in the area of deployment. There is a shelf life and holding requirements for the reagents/standards/onboard blank available from the manufacturer. Care should be taken to calibrate the instrument just prior to deployment using the appropriate standard and reagents that are confirmed to not be expired (and will not run past the expiration date during deployment) and were held in cool dark environments prior to use.

It is recommended that deployments start with a blank cycle, but for some testing a user may wish not to do this.

The 'Warm-Up Interval' allows the external device to stabilize before measuring and should be set in accordance with manufacturers suggestions.

The '# samples to average' allows multiple readings to be averaged. The power selection allows devices that have their own power conditioning to access the instrument batteries directly and thereby increase efficiency. The instrument will need to be flushed after each deployment in seawater (see manual for flushing procedure description).

During pre-deployment evaluations: If any signal intensity is at or near 4000, the channel may be saturated with light, giving erroneous results. Reference and blank signal intensities should be greater than ~1500. Lower intensities will result in higher noise in absorbance and thus pH measurements. However, if during blank measurement signal intensities are low but reference intensities are not, the flow cell needs to be flushed. Dark signals will normally range from ~50 – 200. Higher or erratic dark signals could indicate an electronic problem with the instrument. Onshore the instrument comes with a DI reagent bag to perform flushing. Again, a marine operator can send a command to do this following visual QC inspection of the data or a flushing subroutine can be run periodically at pre-determined intervals, but this would be flushed with seawater *in situ* instead of DI water. Dark signals will normally range from ~50 – 200. Higher or erratic dark signals could indicate an electronic problem with the instrument. All these 'checks' would be part of the Human-in-the-loop QAQC procedures at the marine IOs during predeployment field verification testing or after 'bad' quality data flags appear in the data stream.

Appendix D Sample Factory Characterization Sheet

To be provided at time of DPS signature

Appendix E Collocated CTD Lookup Table for PHWATER Data

Consult the following table to determine the appropriate CTD instrument from which to draw data in order to compute the corrected PHWATER data product. Each pair of collocated instruments is highlighted in blue. Cells highlighted in yellow indicate pairs not co-located as of August 2012, but may be modified through future ECR to make the pairs co-located. (Note that the last four digits of the References Designator may change once the new instrument series and sequence numbers are updated, October 2012).

Reference Designator	Subsite Name	Site Suffix	Node Type	Instrument Class	Depth
GA03FLMA-RI001-07-CTDMO0999	Argentine Basin Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	CTDMO	40
GA03FLMA-RI001-02-PHSEN0999	Argentine Basin Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	PHSEN	40
GA03FLMB-RI001-07-CTDMO0999	Argentine Basin Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	CTDMO	40
GA03FLMB-RI001-02-PHSEN0999	Argentine Basin Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	PHSEN	40
GA01SUMO-RI003-03-CTDMO0999	Argentine Basin Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	20
GA01SUMO-RI003-01-PHSEN0999	Argentine Basin Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	20
GA01SUMO-RI003-06-CTDMO0999	Argentine Basin Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	90
GA01SUMO-RI003-02-PHSEN0999	Argentine Basin Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	100
RS03AXVM-PC03A-08-CTDPFA303	Axial Mooring	AXVM	PC (Platform Interface Controller)	CTDPF	
RS03AXVM-PC03A-10-PHSENA302	Axial Mooring	AXVM	PC (Platform Interface Controller)	PHSEN	
RS03AXVM-SF03A-09-CTDPFA302	Axial Mooring	AXVM	SF (Shallow Profiler Science Float)	CTDPF	
RS03AXVM-SF03A-12-PHSENA301	Axial Mooring	AXVM	SF (Shallow Profiler Science Float)	PHSEN	
CE01ISSM-MF005-01-CTDBP0999	Endurance OR Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	CTDBP	23
CE01ISSM-MF004-02-PHSEN0999	Endurance OR Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	PHSEN	23
CE01ISSM-RI003-01-CTDBP0999	Endurance OR Inshore Surface Mooring	ISSM	RI (Mooring Riser)	CTDBP	5
CE01ISSM-RI002-03-PHSEN0999	Endurance OR Inshore Surface Mooring	ISSM	RI (Mooring Riser)	PHSEN	5
CE04OSHY-PC01B-03-PHSENA106	Endurance OR Offshore Hybrid Profiler Mooring	OSHY	PC (Platform Interface Controller)	PHSEN	200
CE04OSSM-RI002-05-CTDBP0999	Endurance OR Offshore Surface Mooring	OSSM	RI (Mooring Riser)	CTDBP	5
CE04OSSM-RI002-03-PHSEN0999	Endurance OR Offshore Surface Mooring	OSSM	RI (Mooring Riser)	PHSEN	5

CE02SHBP-LJ01D-02-CTDBPD102	Endurance OR Shelf Benthic Pkg	SHBP	LJ (LP Jbox)	CTDBP	
CE02SHBP-LJ01D-06-PHSENC106	Endurance OR Shelf Benthic Pkg	SHBP	LJ (LP Jbox)	PHSEN	0
CE02SHSM-RI002-05-CTDBP0999	Endurance OR Shelf Surface Mooring	SHSM	RI (Mooring Riser)	CTDBP	5
CE02SHSM-RI002-03-PHSEN0999	Endurance OR Shelf Surface Mooring	SHSM	RI (Mooring Riser)	PHSEN	5
CE06ISSM-MF005-01-CTDBP0999	Endurance WA Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	CTDBP	23
CE06ISSM-MF004-02-PHSEN0999	Endurance WA Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	PHSEN	23
CE06ISSM-RI003-01-CTDBP0999	Endurance WA Inshore Surface Mooring	ISSM	RI (Mooring Riser)	CTDBP	5
CE06ISSM-RI002-03-PHSEN0999	Endurance WA Inshore Surface Mooring	ISSM	RI (Mooring Riser)	PHSEN	5
CE09OSSM-RI002-05-CTDBP0999	Endurance WA Offshore Surface Mooring	OSSM	RI (Mooring Riser)	CTDBP	5
CE09OSSM-RI002-03-PHSEN0999	Endurance WA Offshore Surface Mooring	OSSM	RI (Mooring Riser)	PHSEN	5
CE07SHSM-MF004-05-CTDBP0999	Endurance WA Shelf Surface Mooring	SHSM	MF (Multi-Function Node)	CTDBP	78
CE07SHSM-MF004-02-PHSEN0999	Endurance WA Shelf Surface Mooring	SHSM	MF (Multi-Function Node)	PHSEN	78
CE07SHSM-RI002-05-CTDBP0999	Endurance WA Shelf Surface Mooring	SHSM	RI (Mooring Riser)	CTDBP	5
CE07SHSM-RI002-03-PHSEN0999	Endurance WA Shelf Surface Mooring	SHSM	RI (Mooring Riser)	PHSEN	5
GI03FLMA-RI001-07-CTDMO0999	Irminger Sea Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	CTDMO	40
GI03FLMA-RI001-02-PHSEN0999	Irminger Sea Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	PHSEN	40
GI03FLMB-RI001-07-CTDMO0999	Irminger Sea Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	CTDMO	40
GI03FLMB-RI001-02-PHSEN0999	Irminger Sea Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	PHSEN	40
GI01SUMO-RI003-03-CTDMO0999	Irminger Sea Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	20
GI01SUMO-RI003-01-PHSEN0999	Irminger Sea Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	20
GI01SUMO-RI003-06-CTDMO0999	Irminger Sea Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	90
GI01SUMO-RI003-02-PHSEN0999	Irminger Sea Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	100
CP01CNSM-RI002-03-CTDBP0999	Pioneer Central Surface Mooring	CNSM	RI (Mooring Riser)	CTDBP	5

CP01CNSM-RI003-03-PHSEN0999	Pioneer Central Surface Mooring	CNSM	RI (Mooring Riser)	PHSEN	5
CP03ISSM-MF004-04-CTDBP0999	Pioneer Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	CTDBP	93
CP03ISSM-MF004-05-PHSEN0999	Pioneer Inshore Surface Mooring	ISSM	MF (Multi-Function Node)	PHSEN	93
CP03ISSM-RI003-04-CTDBP0999	Pioneer Inshore Surface Mooring	ISSM	RI (Mooring Riser)	CTDBP	5
CP03ISSM-RI002-01-PHSEN0999	Pioneer Inshore Surface Mooring	ISSM	RI (Mooring Riser)	PHSEN	5
CP04OSSM-RI003-04-CTDBP0999	Pioneer Offshore Surface Mooring	OSSM	RI (Mooring Riser)	CTDBP	5
CP04OSSM-RI002-01-PHSEN0999	Pioneer Offshore Surface Mooring	OSSM	RI (Mooring Riser)	PHSEN	5
RS01SBVM-PC01A-08-CTDPFA103	Slope Base Vertical Mooring	SBVM	PC (Platform Interface Controller)	CTDPF	
RS01SBVM-PC01A-10-PHSENA102	Slope Base Vertical Mooring	SBVM	PC (Platform Interface Controller)	PHSEN	
RS01SBVM-SF01A-09-CTDPFA102	Slope Base Vertical Mooring	SBVM	SF (Shallow Profiler Science Float)	CTDPF	
RS01SBVM-SF01A-12-PHSENA101	Slope Base Vertical Mooring	SBVM	SF (Shallow Profiler Science Float)	PHSEN	
GS03FLMA-RI001-07-CTDMO0999	Southern Ocean Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	CTDMO	40
GS03FLMA-RI001-02-PHSEN0999	Southern Ocean Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	PHSEN	40
GS03FLMB-RI001-07-CTDMO0999	Southern Ocean Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	CTDMO	40
GS03FLMB-RI001-02-PHSEN0999	Southern Ocean Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	PHSEN	40
GS01SUMO-RI003-03-CTDMO0999	Southern Ocean Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	20
GS01SUMO-RI003-01-PHSEN0999	Southern Ocean Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	20
GS01SUMO-RI003-06-CTDMO0999	Southern Ocean Surface Mooring	SUMO	RI (Mooring Riser)	CTDMO	90
GS01SUMO-RI003-02-PHSEN0999	Southern Ocean Surface Mooring	SUMO	RI (Mooring Riser)	PHSEN	100
GP03FLMA-RI001-07-CTDMO0999	Station Papa Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	CTDMO	40
GP03FLMA-RI001-02-PHSEN0999	Station Papa Mesoscale Flanking Mooring A	FLMA	RI (Mooring Riser)	PHSEN	40
GP03FLMB-RI001-07-CTDMO0999	Station Papa Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	CTDMO	40
GP03FLMB-RI001-02-PHSEN0999	Station Papa Mesoscale Flanking Mooring B	FLMB	RI (Mooring Riser)	PHSEN	40