OOI

OCEAN OBSERVATORIES INITIATIVE

DATA PRODUCT SPECIFICATION FOR VENT FLUID TEMPERATURE FROM THSPH

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Document Control Sheet

Version	Date	Description	Author
0-01	2014-01-15	Initial Draft	G. Proskurowski
0-02	2014-03-25	Modification after review with vendor	G. Proskurowski
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0-04	2014-04-30	Minor (administrative) modifications to coefficient naming scheme	G. Proskurowski
1-00	2014-05-09	Initial release	E. Chapman

Signature Page

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

OOI Senior Systems Engineer:

Date:2014-05-09

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

OOI CI Signing Authority:

Date:

Table of Contents

1   Abstract

This document describes the computations used to calculate the OOI Level 1 Vent Fluid Temperature data products from the THSPH instrument. The THSPH instrument outputs hexidecimal voltage and resistance data from a series of sensors that is converted off-instrument, using the algorithms described here, to temperatures and chemical species concentrations. This data product specification is specific to two "final" environmental temperature measurements made by the THSPH instrument using a combination of high-temperature thermocouples and reference thermistors, and four "intermediate" temperature products that are particularly useful for tracking instrument health and data quality control. The two temperature measurements are separate from each other, but may be collocated, depending on the deployment. This data product specification includes definition of the raw THSPH hexidecimal output line, and all of the data manipulations to calculate temperature products from the raw data.

2   Introduction

2.1   Author Contact Information

Please contact Giora Proskurowski (giora@uw.edu) or the Data Product Specification lead (DPS@lists.oceanobservatories.org) for more information concerning the computation and other items in this document.

2.2   Metadata Information

2.2.1   Data Product Name

The OOI Core Data Product Name for this product is
- THSPHTE

The OOI Core Data Product Descriptive Name for this product is
- Vent Fluid Temperature from THSPH

2.2.2   Data Product Abstract (for Metadata)

The OOI Level 1 Vent Fluid Temperature core data product is the measured temperature at the sample inlet of the THSPH instrument.

2.2.3   Computation Name

Not required for data products.

2.2.4   Computation Abstract (for Metadata)

This algorithm parses the OOI Level 1 Vent Fluid Temperature core data product, from the instrument data string.

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
- Fluid temperature

2.2.7   Similar Data Products

Similar data products that may be confused with this data product by users or CI include: "Seafloor Temperature", "Vent Fluid Temperature from TRHPH", and/or "Vent Fluid Temperature from RASFL".

While all of these products measure temperature at seafloor hydrothermal vents, they use different methodologies.

2.3   Instruments

For information on the instruments from which the L1 Vent Fluid Temperature core data product inputs are obtained, see the THSPH Data Processing Flow document (DCN 1342-00120). This document contains information on instrument classes and make/models; it also describes the flow of data from the instrument 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.

2.4   Literature and Reference Documents

Not applicable.

2.5   Terminology

2.5.1   Definitions

Not Applicable.

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).

2.5.3   Variables and Symbols

The following variables and symbols are defined here for use throughout this document. Because there are two independent thermocouple ("tc") temperature measurements made, the "_H" or "_L" is appended to the appropriate variables to associate them with the "High" or "Low" thermocouple. The deployment strategy is to place one thermocouple ("_H") in the high temperature fluid, with the other thermocouple ("_L") out of the strong flow. Both thermocouples are referenced to a thermistor ("ts") at the cold-junction reference ("ts_r") inside the sensor wand. Additionally, there is an onboard thermistor inside the electronics pressure housing that serves as a good check for bench-testing data quality and for in-situ housing health.

tc_rawhex_H = raw hexadecimal "H" thermocouple output
tc_rawdec_L = raw decimal "L" thermocouple output
ts_rawhex_r = raw hexadecimal reference thermistor output
ts_rawhex_b = raw hexadecimal board thermistor output
tc_rawdec_H = raw decimal "H" thermocouple output
tc_rawdec_L = raw decimal "L" thermocouple output
ts_rawdec_r = raw decimal reference thermistor output
ts_rawdec_b = raw decimal board thermistor output
$V\_tc\_eng\_H$ = engineering "H" thermocouple output, V
$V\_tc\_eng\_L$ = engineering "L" thermocouple output, V
$R\_ts\_eng\_r$ = engineering reference thermistor output, Ω
$R\_ts\_eng\_b$ = engineering board thermistor output, Ω
$V\_tc\_actual\_H$ = calibrated "H" thermocouple voltage, V
$V\_tc\_actual\_L$ = calibrated "L" thermocouple voltage, V
$R\_ts\_actual\_r$ = calibrated reference thermistor resistance, Ω
$R\_ts\_actual\_b$ = calibrated board thermistor resistance, Ω
T_tc_H = thermocouple "H" temperature, ℃
T_tc_L = thermocouple "L" temperature, ℃
T_ts_r = reference thermistor temperature, ℃
T_ts_b = board thermistor temperature, ℃

T_H_uncal = uncalibrated temperature, °C, at the sample inlet ("H")
T_L_uncal = uncalibrated temperature, °C, near vent ("L")
T_H = temperature, °C, at the sample inlet ("H")
T_L = temperature, °C, near vent ("L")

$(c_4,c_3,c_2,c_1,c_0)\_e2l\_H$ = correction coefficients applied to thermocouple "H" "engineering to lab"
$(c_4,c_3,c_2,c_1,c_0)\_e2l\_L$ = correction coefficients applied to thermocouple "L" "engineering to lab"
$(c_4,c_3,c_2,c_1,c_0)\_e2l\_r$ = correction coefficients applied to reference thermistor "engineering to lab"
$(c_4,c_3,c_2,c_1,c_0)\_e2l\_b$ = correction coefficients applied to board thermistor "engineering to lab"
$(c_5,c_4,c_3,c_2,c_1,c_0)\_l2s\_H$ = correction coefficients applied to thermocouple "H" "lab to scientific"
$(c_5,c_4,c_3,c_2,c_1,c_0)\_l2s\_L$ = correction coefficients applied to thermocouple "L" "lab to scientific"
$(c_4,c_3,c_2,c_1,c_0)\_l2s\_r$ = correction coefficients applied to reference thermistor "lab to scientific"
$(c_4,c_3,c_2,c_1,c_0)\_l2s\_b$ = correction coefficients applied to board thermistor "lab to scientific"
$(c_1,c_0)\_s2f\_H$ = correction coefficients applied to absolute temperature "H" "scientific to final"
$(c_1,c_0)\_s2f\_L$ = correction coefficients applied to absolute temperature "L" "scientific to final"

Correction coefficients applied to the general formula $c_5*x^4+c_4*x^4+c_3*x^3+c_2*x^2+c_1*x+c_0$.

3 Theory

3.1 Description

Temperature is measured at the sample inlet using a thermocouple referenced to a thermistor at the electrical cold-junction in the sensor wand. The raw measurements are each calibrated using a linear correction, and then converted to °C using equations associated with the measurement technique. Finally the thermocouple and thermistor measurements are combined to yield an absolute temperature. Four temperature measurements are being made: Tc_H (thermocouple in high temperature fluid), Tc_L (thermocouple in low temperature near vent), Ts_r (reference thermistor at cold-junction), Ts_b (thermistor inside electronics pressure housing).

3.2 Mathematical Theory

Not Applicable.

3.3 Known Theoretical Limitations

Not Applicable.

3.4 Revision History

No revisions to date.

4 Implementation

4.1 Overview

Thermocouple and thermistor outputs are parsed from the full response string, and converted to decimal. The raw decimal output is converted to engineering units of volts (V) or ohms (R, units of Ω), and then to calibrated units of volts or ohms. Each sensor output is then converted to temperature, °C, and then the thermocouple and reference thermistor values are combined to yield an absolute temperature, °C, at the vent and near vent measurement sites.

4.2 Inputs

- Raw THSPH hexadecimal string

Input Data Formats:

The raw THSPH data output is a 35 character hexadecimal string, initiated by "aH" and terminated by "#". The 32 remaining characters represent 8 data channels each a 4-character hexadecimal string:

       CH1: High temperature ceramic electrode
       CH2: Low T Reference electrode
       CH3: H_2 electrode
       CH4: S^{2-} electrode
       CH5: thermocouple 1
       CH6: thermocouple 2
       CH7: reference thermistor
       CH8: on board thermistor input

Example THSPH data output:

a	H	C11	C12	C13	C14	C21	C22	C23	C24	C31	C32	C33	C34	C41	C42	C43	C44	C51	C52	C53	C54	C61	C62	C63	C64	C71	C72	C73	C74	C81	C82	C83	C84	#
			CH1				CH2				CH3				CH4				CH5				CH6				CH7				CH8			

C11-C14 is the data of CH1, C21-C24 is the data of CH2, etc

For the calculation of Vent Fluid Temperature from THSPH channels 5,6, 7 and 8 must be ingested.

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 document (DCN 1342-00120). This processing flow document contains 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.

The processing flow for the temperature computation is as follows:

Timestamp to be associated with all THSPH data products is the timestamp from the Digiport.

Step 1:
Parse the following raw hexadecimal outputs from the THSPH data string:
       tc_rawhex_H = CH51-CH54
       tc_rawhex_L = CH61-CH64
       ts_rawhex_r = CH71-CH74
       ts_rawhex_b = CH81-CH84

Step 2:
Convert hex strings to decimal
       tc_rawdec_H = hex2dec(tc_rawhex_H)
       tc_rawdec_L = hex2dec(tc_rawhex_L)
       ts_rawdec_r = hex2dec(ts_rawhex_r)
       ts_rawdec_b = hex2dec(ts_rawhex_b)

Step 3:
Transform raw decimal output to engineering values, units of Volts (units V for the "tc") and ohms (Ω for the "ts")
       V_tc_eng_H = (tc_rawdec_H * 0.25 – 1024)/61606
       V_tc_eng_L = (tc_rawdec_L * 0.25 – 1024)/61606
       R_ts_eng_r = (10000 * ts_rawdec_r *0.125)/(2048 - ts_rawdec_r * 0.125)
       R_ts_eng_b = (10000 * ts_rawdec_b *0.125)/(2048 - ts_rawdec_b * 0.125)

Step 4:

Transform engineering values to lab calibrated values, units of Volts (units V for the "tc") and ohms (Ω for the "ts"), a polynomial correction

$$V\_tc\_actual\_H = c4\_e2l\_H*(V\_tc\_eng\_H)^4 + … + c1\_e2l\_H*(V\_tc\_eng\_H) + c0\_e2l\_H$$
$$V\_tc\_actual\_L = c4\_e2l\_L*(V\_tc\_eng\_L)^4 + … + c1\_e2l\_L*(V\_tc\_eng\_L) + c0\_e2l\_L$$
$$R\_ts\_actual\_r = c4\_e2l\_r*(R\_ts\_eng\_r)^4 + … + c1\_e2l\_r*(R\_ts\_eng\_r) + c0\_e2l\_r$$
$$R\_ts\_actual\_b = c4\_e2l\_b*(R\_ts\_eng\_b)^4 + … + c1\_e2l\_b*(R\_ts\_eng\_b) + c0\_e2l\_b$$

Where (c4,c3,c2,c1,c0)_x are operator supplied coefficients for polynomial in the form of c4*x^4+c3*x^3+c2*x^2+c1*x+c0. The coefficients are unique to the sensor deployed, must be settable by the marine operator (e.g. in a version controlled lookup table), and preserved in the metadata.

Step 5:
Transform calibrated engineering values to scientific values, units of temperature in °C (unnecessary parentheses are provided as a visual aid). These equations are subject to change, so it may be wise to set them up as a lookup tables similar to Step 4.

Initially the following constants can be used with the thermocouple and thermistor materials supplied for the 2014 deployments:

(c5,c4,c3,c2,c1,c0)_l2s_(H,L) = (0.000000932483, -0.000122268, 0.00702, -0.23532, 17.06172, -0.00444,)

(c4,c3,c2,c1,c0)_l2s_(r,b) = (1.38009E-4, -0.01432, 0.53886, -9.58863, 79.12599)

$$T\_tc\_H = (c5\_l2s\_H * ((V\_tc\_actual\_H * 1000)^5)) + (c4\_l2s\_H * ((V\_tc\_actual\_H * 1000)^4)) + (c3\_l2s\_H *((V\_tc\_actual\_H * 1000)^3)) + (c2\_l2s\_H *((V\_tc\_actual\_H *1000)^2)) + (c1\_l2s\_H * (V\_tc\_actual\_H * 1000)) + c0\_l2s\_H$$

$$T\_tc\_L = (c5\_l2s\_L * ((V\_tc\_actual\_L * 1000)^5)) + (c4\_l2s\_L * ((V\_tc\_actual\_L * 1000)^4)) + (c3\_l2s\_L *((V\_tc\_actual\_L * 1000)^3)) + (c2\_l2s\_L *((V\_tc\_actual\_L *1000)^2)) + (c1\_l2s\_L * (V\_tc\_actual\_L * 1000) + c0\_l2s\_L$$

$$T\_ts\_r = (c4\_l2s\_r * (R\_ts\_actual\_r)^4) + (c3\_l2s\_r * (R\_ts\_actual\_r)^3) + (c2\_l2s\_r * (R\_ts\_actual\_r)^2) + (c1\_l2s\_r * R\_ts\_actual\_r) + c0\_l2s\_r$$

$$T\_ts\_b = (c4\_l2s\_b * (R\_ts\_actual\_b)^4) + (c3\_l2s\_b * (R\_ts\_actual\_b)^3) + (c2\_l2s\_b * (R\_ts\_actual\_b)^2) + (c1\_l2s\_b * R\_ts\_actual\_b) + c0\_l2s\_b$$

Step 6:
Calculate absolute temperature at thermocouple measurement sites, units of temperature in °C:

$$T\_H\_uncal = T\_ts\_r + T\_tc\_H$$
$$T\_L\_uncal = T\_ts\_r + T\_tc\_L$$

Step 7:
Apply final linear calibration to the T_H_uncal and T_L_uncal data

$$T\_H = c1\_s2f\_H*(T\_H\_uncal) + c0\_s2f\_H$$
$$T\_L = c1\_s2f\_L*(T\_L\_uncal) + c0\_s2f\_L$$

4.4 Outputs

The outputs of the parsing and calculations are

Scientific L1 Data Products

- T_H: Temperature at high temperature location (position of thermocouple "H"), °C, %.2f. (Digi timestamp—this will be used for timestamping for all data lines); this Scientific L1 Data Product THSPHTE-TH.
- T_L: Temperature at low temperature location (position of thermocouple "L"), °C, %.2f. (Digi timestamp); this Scientific L1 Data Product THSPHTE-TL.
- T_ts_r: Reference thermistor Temperature, °C, %.2f. (Digi timestamp); this is Scientific L1 Data Product THSPHTE-REF
- T_tc_H: Thermocouple temperature position "H" (high temperature vent fluid), °C, %.2f. (Digi timestamp); this is Scientific L1 Data Product THSPHTE-TCH
- T_tc_L: Thermocouple temperature position "L" (low temperature near vent), °C, %.2f. (Digi timestamp); this is Scientific L1 Data Product THSPHTE-TCL
- T_ts_b: Board thermistor Temperature, °C, %.2f. (Digi timestamp); this is Scientific L1 Data Product THSPHTE-INT

The metadata that must be included with the output are
- calibration coefficients used
- Description of position of thermocouple sensors H, and L

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

Time stamp should be the time from the Digiport, rather than from the data string, the OMS or OOInet.

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.

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.

The test data set below provides a few data points, see THSPHTE_Test_Data_Set_v4.xls for full set.

Input:

```
aH200B200720C420A1108D3E8C22421FFC#
aH200B200720C420A1108D3E8C22421FFC#
aH2009200820C220A0108C3E8922361FF9#
```

Assuming the following calibration coefficients (c5,c4,c3,c2,c1,c0)_(e2l,l2s)_x where $c_5 \cdot x^5 + c_4 \cdot x^4 + c_3 \cdot x^3 + c_2 \cdot x^2 + c_1 \cdot x + c_0$ and (c1,c0)_s2f_x where $c_1 \cdot x + c_0$.

	c5	c4	c3	c2	c1	c0
(c4,c3,c2,c1,c0)_e2l_H	0	0	0	0	1	-0.00055
(c4,c3,c2,c1,c0)_e2l_L	0	0	0	0	1	-0.00055

(c4,c3,c2,c1,c0)_e2l_r	0	0	4.54486E-13	3.82028E-10	0.00099151	0.05935
(c4,c3,c2,c1,c0)_e2l_b	0	0	4.54486E-13	3.82028E-10	0.00099151	0.05935
(c5,c4,c3,c2,c1,c0)_l2s_H	9.32483E-07	-0.00444	17.06172	-0.23532	0.00702	-0.000122268
(c5,c4,c3,c2,c1,c0)_l2s_L	9.32483E-07	-0.00444	17.06172	-0.23532	0.00702	-0.000122268
(c4,c3,c2,c1,c0)_l2s_r	0	79.12599	-9.58863	0.53886	-0.01432	0.000138009
(c4,c3,c2,c1,c0)_l2s_b	0	79.12599	-9.58863	0.53886	-0.01432	0.000138009
(c1,c0)_s2f_H	0	0	0	0	0.95567	1.68019
(c1,c0)_s2f_L	0	0	0	0	0.95567	1.68019
H thermocouple directly in Diva vent fluid						
L thermocouple in seawater at end of sensor wand						

Output:

(Digi timestamp = DTS)

[DTS T_H   T_L   T_ts_r T_tc_H T_tc_L T_ts_b]

DTS	T_H	T_L	T_ts_r	T_tc_H	T_tc_L	T_ts_b
DTS	20.54	630.89	19.36	0.37	639.04	23.06
DTS	20.54	630.89	19.36	0.37	639.04	23.06
DTS	20.54	630.80	19.43	0.30	638.87	23.08

L1 product includes the High Temperature and Low Temperature products (T_H, T_L), the reference thermistor (T_ts_r), the thermocouple temperatures (T_tc_H, T_tc_L) and the electronics housing thermistor (T_ts_b) merged with the time stamp information. The 6 temperature values can be stored in an array, but should have the full functionality during plotting and downloads of 6 different parameters.

In addition, the output should have metadata fields containing the 6 sets of correction coefficients, and a short description of the position of the sensors T_H and T_L.

Appendix A   Example Code

```
def parse(self, sample):
        ch1hex = sample[2:6]
        ch2hex = sample[6:10]
        ch3hex = sample[10:14]
        ch4hex = sample[14:18]
        ch5hex = sample[18:22]  #tc_rawhex_H
        ch6hex = sample[22:26]  #tc_rawhex_L
        ch7hex = sample[26:30]  #ts_rawhex_r
        ch8hex = sample[30:34]  #ts_rawhex_b
#        print "ch1 %s ch2 %s ch3 %s ch4 %s ch5 %s ch6 %s ch7 %s ch8 %s \r" %
(ch1hex,ch2hex,ch3hex,ch4hex,ch5hex,ch6hex,ch7hex,ch8hex)
        ch5dec = int(ch5hex,16) #tc_rawdec_H
        ch6dec = int(ch6hex,16) #tc_rawdec_L
        ch7dec = int(ch7hex,16) #ts_rawdec_r
        ch8dec = int(ch8hex,16) #tc_rawdec_b
#        print "ch5 %f ch6 %f ch7 %f ch8 %f \r" % (ch5dec,ch6dec,ch7dec,ch8dec)
        vch5 = (ch5dec*0.25-1024)/61606    #V_tc_eng_H
        vch6 = (ch6dec*0.25-1024)/61606    #V_tc_eng_L
        rch7 = (10000*ch7dec*0.125)/(2048-ch7dec*0.125)   #R_ts_eng_r
        rch8 = (10000*ch8dec*0.125)/(2048-ch8dec*0.125)   #R_ts_eng_b
#        print "vch5 %f vch6 %f rch7 %f rch8 %f \r" % (vch5,vch6,rch7,rch8)
        vch5act = vch5 - 0.00055   #V_tc_actual_H
        vch6act = vch6 - 0.00055   #V_tc_actual_L
        rch7act = 0.05935 + 0.00099151*rch7 + 3.82028e-10*rch7**2 +4.54486e-13*rch7**3
#R_ts_actual_r
        rch8act = 0.05935 + 0.00099151*rch8 + 3.82028e-10*rch8**2 +4.54486e-13*rch8**3
#R_ts_actual_r
#        print "vch5act %f rch7act %f rch8act %f \r" % (vch5act,rch7act,rch8act)
        Tch5 = -0.00444 + 17.06172*vch5act*1000 - 0.23532*(vch5act*1000)**2 +
0.00702*(vch5act*1000)**3 - 0.000122268*(vch5act*1000)**4 +
0.000000932483*(vch5act*1000)**5    #T_tc_H
        Tch5 = -0.00444 + 17.06172*vch6act*1000 - 0.23532*(vch6act*1000)**2 +
0.00702*(vch6act*1000)**3 - 0.000122268*(vch6act*1000)**4 +
0.000000932483*(vch6act*1000)**5    #T_tc_L
        Tch7= 79.12599 - 9.58863*rch7act + 0.53886*rch7act**2 - 0.01432*rch7act**3 +
1.38009e-4*rch7act**4   #T_ts_r
        Tch8= 79.12599 - 9.58863*rch8act + 0.53886*rch8act**2 - 0.01432*rch8act**3 +
1.38009e-4*rch8act**4   #T_ts_b
        TH = Tch5 + Tch7    #T_H_uncal
        TL = Tch6 + Tch7    #T_L_uncal
        THcal = 1.68019 + 0.95567*TH   #T_H
        TLcal = 1.68019 + 0.95567*TL   #T_L
#        print "Tch5 %.2f Tch7 %.2f Tch8 %.2f TH %.2f THcal %.2f \r" % (Tch5, Tch7, Tch8, TH,
THcal)
        print " %.2f THcal %.2f thermistor %.2f board" % (THcal, Tch7, Tch8)
        return THcal
```

Appendix B   Output Accuracy

The accuracy of the L1 product, which includes a linear correction step, is similar to the accuracy of the thermistor and thermocouple component sensors.

The OOI-RSN requirements for the accuracy and precision of the Vent Fluid Temperature from TSHPH measurement, as represented in DOORS are:

> The vent fluid pH-H2S-H2-T chemistry instrument shall measure temperature with an accuracy of 1°C.   <L4-RSN-IP-RQ-728>

Factory reported accuracy for NTC thermistor is 0.2°C, and for Type E thermocouple is 1.0°C. When used in combination and calibrated in lab accuracy is closer to that of the thermistor.

Appendix C   Sensor Calibration Effects

The three temperature sensors are calibrated in ice water and boiling water and compared to a laboratory Hg thermometer. Data were collected over the network. The standard deviation of all probes was less than 0.1°C at zero and 100, and the accuracy was within 0.5°C.