DATA PRODUCT SPECIFICATION FOR VENT FLUID TEMPERATURE FROM TRHPH

Version 1-03
Document Control Number 1341-00150
2014-05-02

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Document Control Sheet

Version	Date	Description	Author
0-01	2011-12-22	Initial Draft	G. Proskurowski
0-02	2012-01-04	Modified using test data from Lilley Lab	G. Proskurowski
0-03	2012-01-11	Updated after review by O. Kawka and S. Webster	G. Proskurowski
0-04	2012-01-25	Updated after informal review, incorporating feedback from S. Ackleson, S. Banahan, D. Kelley, M. Lilley	G. Proskurowski
0-05	2012-02-06	Updated after formal review, incorporating feedback from CI, S. Webster, and S. Banahan	G. Proskurowski
1-00	2012-02-15	Initial release	E. Chapman
1-01	2012-03-23	Administrative (title) change related to Data Products Spreadsheet (DCN 1340-00000 Version 1-03)	E. Griffin
1-02	2014-03-25	Update method provided after vendor calibration	G. Proskurowski
1-03	2014-05-02	Administrative changes to nomenclature	G. Proskurowski

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Signature Page

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

OOI Chief Systems Engineer: ____

Date: 2011-02-15

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: 2011-02-15

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Table of Contents

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1 Abstract

This document describes the computation used to calculate TRHPHTE, the OOI Level 1 Vent Fluid Temperature From TRHPH data product. This data product is the result of temperature measurements made using the Temperature-Resistivity Probe Instrument (TRHPH) placed in a high temperature hydrothermal vent. For the Temperature-Resistivity Probe Instrument, this data product is calculated from standard thermocouple and thermistor response curves adjusted to the custom instrument design and corrected by laboratory calibration. This primary intended use of this document is for OOI programmers to construct appropriate processes to create the L1 Temperature data product.

Note: As multiple measurements of vent fluid temperature are being made with different instruments, the name of this data product is amended with the specific instrument name. Hence, the very specific data product name "Vent Fluid Temperature From TRHPH".

2 Introduction

2.1 Author Contact Information

Please contact the Data Product Specification lead (DPS@lists.oceanobservatories.org) or the author Giora Proskurowski (giora@uw.edu) 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
- TRHPHTE

The OOI Core Data Product Descriptive Name, to be used as an instrument title in ION, for this product is
- OOI Level 1 Vent Fluid Temperature From TRHPH

2.2.2 Data Product Abstract (for Metadata)

The OOI Level 1 Vent Fluid Temperature From TRHPH core data product is computed using the industry standard thermocouple and thermistor response curves adjusted to laboratory calibrations.

2.2.3 Computation Name

Vent Fluid Temperature From TRHPH Computation

2.2.4 Computation Abstract (for Metadata)

This computation computes the OOI Level 1 Vent Fluid Temperature From TRHPH core data product, which is calculated using data from a thermocouple and reference thermistor on the TRHPH instrument sensor package.

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
- Vent temperature

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2.2.7 Similar Data Products

N/A

2.3 Instruments

For information on the instruments from which the L1 Vent Fluid Temperature From TRHPH core data product inputs are obtained, see the TRHPH Processing Flow document (DCN 1342-00150), which describes the flow of data from the TRHPH 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

Larson, B.I., Olson, E.J, and Lilley M.D. (2007). "In situ measurement of dissolved chloride in high temperature hydrothermal fluids." *Geochimica et Cosmochimica Acta* **71**, 2510-2523. *(see DPS Artifacts >> TRHPHTE >> TRHPHTE_Larson_2007.pdf)*

NIST ITS-90 Thermocouple Database, NIST Standard Reference Database 60, Version 2.0 (Web Version). Database based: Temperature-Electromotive Force Reference Functions and Tables for the Letter-Designated Thermocouple Types Based on the ITS-90. *Natl. Inst. Stand. Technol. Monograph 175*; 1993. 630 p. http://srdata.nist.gov/its90/main/its90_main_page.html *(see DPS Artifacts >> >> TRHPHTE >> TRHPHTE_NIST-ITS-90_1993.txt)*

2.5 Terminology

2.5.1 Definitions

Thermocouple, Type K: Sensor for measuring temperature consisting of two dissimilar metals, joined together at one end. "Type K" refers to the calibration related to a chromel-alumel thermocouple wire. The measured voltage of a thermocouple circuit is related to the temperature relative to the cold junction, and thus a reference temperature at the cold junction is necessary for measurement of accurate total temperature.

Thermistor: Sensor for measuring temperature based on the resistance properties of the sensor material. When a thermistor is located at the cold junction of a thermocouple, total temperature can be measured at the thermocouple tip.

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 maintained on a Dynamic Object Oriented Requirements System tool (DOORS). The following acronyms and abbreviations are defined here for use throughout this document.

N/A

2.5.3 Variables and Symbols

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

T	Temperature (℃) – total temperature, corrected using lab calibration
T_ts	Thermistor Temperature (℃)
V_tc	Thermocouple Voltage raw (V)

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V_ts	Thermistor Voltage (V)
tc_slope	Laboratory based calibration coefficient
ts_slope	Laboratory based calibration coefficient
c3,c2,c1,c0	Coefficients for a 3rd degree polynomial fit of lab calibration correction curve, in the form "c3*x^3+c2*x^2+c1*x+c0". These coefficients are known as of March 2014, and should not change for the foreseeable future, but should reside in a lookup table should they change.

3 Theory

3.1 Description

For both the thermocouple and thermistor, temperature is calculated by converting sensor output voltage to °C using standard response curves for the expected temperature range (0-400°C for the thermocouple, 0-30°C for the thermistor). The thermocouple conversion from voltage to °C is based on the NIST standard response curve for Type K thermocouples. The thermistor conversion from voltage to °C utilizes the manufacturer's calibration adjusted for the designed circuitry of the sensor to linearize the function over the limited temperature range of interest (0-30°C). Because the thermocouple measures the temperature relative to the cold junction of the circuit (reference), a correction must be applied to the thermocouple voltage (V_tc) dependent on the temperature at the thermistor. This correction is applied differently depending on the thermistor temperature, with the output being the final temperature (T), reflecting the laboratory calibration of the specific thermocouple/thermistor sensor pair. The laboratory calibration of the temperature sensor utilizes a NIST traceable dry block bench top temperature calibration unit, and a water bath with temperature measured by a NIST traceable thermocouple.

3.2 Mathematical Theory

The following formulae are used to calculate the L1 Vent Fluid Temperature From TRHPH data product, T.

Thermistor T_ts:
T_ts = 27.50133 – 17.2658*V_s + 15.83424/V_s

Laboratory Calibrated T, for V_tc <= 0:
T = T_ts

Laboratory Calibrated T, for T_ts > 10:
T = (V_tc + (c3*(T_ts)^3 + c2*(T_ts)^2 + c1*(T_ts) + c0))*244.97
With (c3,c2,c1,c0) = (-1e-6, 7e-5, 0.0024, 0.015)

Laboratory Calibrated T, for 0 < T_ts <= 10:
T = (V_tc + V_tc*244.97*tc_slope + T_ts*ts_slope)*244.97
With tc_slope and ts_slope specific to the calibrated probe

3.3 Known Theoretical Limitations

The equation for converting thermistor voltage to temperature is only valid in the range 0 < T_s < 45 °C.

3.4 Revision History

Document revised March 25, 2014 to reflect new calibration procedure at vendor.

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4 Implementation

4.1 Overview

The computation of temperature is implemented using a series of simple mathematical equations to convert from raw voltages to temperature, and then adjust for a laboratory calibration. The example Matlab code presented in the Appendix A illustrates the sequence of calculations.

4.2 Inputs

- L0 Reference Temp Volts (V_ts, thermistor voltage, word 8)
- L0 Resistivity Temp Volts (V_tc, thermocouple voltage, word 10)
- Instrument metadata calibration curve coefficients:
  a,b,c,d, where $c3*x^3 + c2*x^2 + c1*x + c0$ (not probe specific, but possible to change in the future)
  tc_slope (probe specific)
  ts_slope (probe specific)

Inputs are five character, fixed width, floating point numbers, %5.3f.

In addition, calibration curve coefficients (c3,c2,c1, and c0, where $c3*x^3 + c2*x^2 + c1*x + c0$) and tc_slope and ts_slope must be provided from the instrument metadata. These values are constants specific to the deployed sensor.

Input Data Formats:
Instrument provides a single line of ASCII text data with X "words". V_s is word 8, V_c is word 10. Each input word of interest is a fixed width five character number, including the decimal point, floating point value (%5.3f).

Example TRHPH Raw Data Output Line (with exact formatting)

0.135 0.681 3.426 0.000 0.021 0.079 0.911 1.929 2.40 1.318 325.3 9.2
Input V_ts is highlighted in red, and V_tc in blue.

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 1342-00150). 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 executed.

The processing flow for the temperature computation is as follows (in Matlab syntax):

Step 1:
Calculate thermistor reference voltage, T_ts, from V_ts:
T_ts = 27.50133 – 17.2658*V_ts + 15.83424/V_ts
Step 2:
Evaluate logical arguments to arrive at the correct calculation for T:
if V_tc <= 0 then Step 3
if V_tc > 0 AND T_ts > 10 then Step 4
if V_tc > 0 AND 0 < T_ts <= 10 then Step 5

Step 3: Calculate L1 Vent Fluid Temperature from TRHPH data product, T, the calibrated temperature, from T_ts:

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if V_tc <= 0
T = T_ts

Step 4:
Calculate L1 Vent Fluid Temperature from TRHPH data product, T, the calibrated temperature, from V_tc and T_ts
if V_tc > 0 && T_ts >10
T = (V_tc + (c3*(T_ts)^3 + c2*(T_ts)^2 + c1*(T_ts) + c0))*244.97
With (c3,c2,c1,c0) = (-1e-6, 7e-5, 0.0024, 0.015)

Step 5:
Calculate L1 Vent Fluid Temperature from TRHPH data product, T, the calibrated temperature, from V_tc and T_ts
if V_tc > 0 && 0 < T_ts <=10
T = (V_tc + V_tc*244.97*tc_slope + T_ts*ts_slope)*244.97
With tc_slope and ts_slope specific to the calibrated probe deployed (example slopes: % tc_slope=4.22e-5, ts_slope=.003)

4.4 Outputs

The outputs of the temperature computation are:

- Temperature, T, in °C, as a 5 character floating point number, %.1f.

Also included, as an output is the intermediate data product, T_ts, the thermistor (reference temperature). This is an important data product for monitoring and troubleshooting the instrument. T_ts is, in essence, engineering data that should not be confused with scientific data. T_ts is available to those looking at the Vent Fluid Temperature from TRHPH product and its provenance, but does not represent a scientifically meaningful environmental temperature measurement. T_ts is not considered a "core data product":

- Thermistor temperature (reference), T_ts, as a floating point number, %.2f

See Appendix B for a discussion of the accuracy of the 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

- One TRHPH probe, sample rate of 1 sample every 12 seconds.

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 temperature output. Inputs to Vent Fluid Temperature from TRHPH product, V_ts and V_tc, are highlighted in red and blue, respectively. Another example dataset is provided in the spreadsheet TRHPH_DPS_data_example.xls.

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Sample TRHPH Data Output

V_R1	V_R2	V_R3				ORP_V	V_ts	T_ts	V_tc	T_u	
0.906	4.095	4.095	0.000	0.019	0.076	1.806	1.506	12.01	0.000	12.0	9.2
0.890	4.095	4.095	0.000	0.021	0.077	1.541	1.479	12.67	0.015	16.3	9.2
0.891	4.095	4.095	0.000	0.021	0.079	1.810	1.926	2.47	0.001	2.7	9.2
0.184	0.915	4.064	0.000	0.022	0.074	0.735	1.932	2.34	0.274	69.5	9.2
0.198	1.002	4.095	0.000	0.020	0.075	0.745	1.927	2.45	0.306	77.4	9.2
0.172	0.857	4.082	0.000	0.022	0.073	0.715	1.930	2.38	0.393	98.7	9.2
0.183	0.926	4.076	0.000	0.020	0.079	0.775	1.929	2.40	0.383	96.2	9.2
0.233	1.182	4.072	0.000	0.021	0.075	0.799	1.930	2.38	0.388	97.4	9.2
0.146	0.747	3.634	0.000	0.018	0.078	0.757	1.930	2.38	0.469	117.3	9.2
0.134	0.681	3.405	0.000	0.021	0.078	0.542	1.931	2.36	1.077	266.2	9.2
0.131	0.673	3.293	0.000	0.021	0.078	0.831	1.926	2.47	1.288	318.0	9.2
0.133	0.678	3.396	0.000	0.019	0.077	0.867	1.926	2.47	1.305	322.2	9.2
0.135	0.681	3.409	0.000	0.021	0.079	0.911	1.928	2.43	1.319	325.5	9.2
0.135	0.681	3.426	0.000	0.021	0.079	0.911	1.929	2.40	1.318	325.3	9.2

The test data set below provides the results of the Vent Fluid Temperature From TRHPH calculation for the above example data set, using tc_slope=4.22e-5 and ts_slope=.003.

Inputs		Intermediate Calculations	Output
V_ts	V_c	T_ts	T
[V]	[V]	[deg C]	[deg C]
1.506	0.000	12.01	12.0
1.479	0.015	12.67	17.1
1.926	0.001	2.47	2.1
1.932	0.274	2.34	69.5
1.927	0.306	2.45	77.5
1.930	0.393	2.38	99.0
1.929	0.383	2.40	96.6
1.930	0.388	2.38	97.8
1.930	0.469	2.38	117.8
1.931	1.077	2.36	268.3
1.926	1.288	2.47	320.6
1.926	1.305	2.47	324.8
1.928	1.319	2.43	328.2
1.929	1.318	2.40	328.0

In addition, T_ts will be output as a data product similar to engineering data that is relevant to the trouble shooting of the instrument, but is not scientifically relevant.

Appendix A Example Code

This Appendix contains an example Matlab subroutine to calculate L1 Product Temperature, as well as metadata outputs Thermistor Temperature and Thermocouple Temperature. This code has been verified by the originators using examples from raw TRHPH data.

```
function [T_ts, T] = resT(V_ts, V_tc, tc_slope, ts_slope)

% This function computes Temperature from raw Temp-Resistivity Probe
% measurements using a thermistor and a thermocouple.  Initial inputs are
% the raw voltages for the thermistor (V_s) and thermocouple (V_c) and
% laboratory calibration coefficients tc_slope, ts_slope. Coefficients
% c3,c2,c1 and c0 are not probe specific and are not passed as arguments.

% The following coefficients are derived from a 3rd degree polynomial fit
% of a calibration curve, where c3*x^3+c2*x^2+c1*x+C0.  These will be
% entered as input metadata. These coefficients are not expected to
% change in the near future.

C3= -1e-6; c2 = 7e-5; c1 = 0.0024; c0 = 0.015;
% tc_slope=4.22e-5; %example
% ts_slope=.003;    %example

T_ts = 27.50133 - 17.2658*V_ts + 15.83424/V_ts; %thermistor temperature

if V_tc <= 0         % thermocouple = thermistor
    T = T_ts;

else
    if T_ts > 10
       T = (V_tc + (c3*(T_ts)^3 + c2*(T_ts)^2 + c1*(T_ts) + c0))*244.97;
    else
       T = (V_tc + V_tc*244.97*tc_slope + T_ts*ts_slope)*244.97;  % for most deployment
scenarious
    end
end


T_ts
T
```

Appendix B Output Accuracy

The accuracy of the Temperature calculated as described herein is a function of the accuracy of the sensor measurements (thermistor and thermocouple) and the applied calibration. The specified accuracy outlined in the Technical Specification document (4320-00022) is:

±0.5 for Temperature is (TEMP-003)

Accuracy Requirement in DOORS
Temperature shall be measured with an accuracy of ±0.5 °C. <L4-RSN-IP-RQ-581>

Appendix C Sensor Calibration Effects

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