NEON Algorithm Theoretical Basis Document – Single Aspirated Air Temperature

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LIST OF TABLES AND FIGURES

1 DESCRIPTION

Contained in this document are details concerning temperature measurements made at all NEON sites. Specifically, the processes necessary to convert "raw" sensor measurements into meaningful scientific units and their associated uncertainties are described. Temperature will be continuously monitored by NEON at core and relocatable sites by two methods. Temperature for the top of the tower will be derived from the triple redundant aspirated air temperature sensor and will be discussed in additional documents. This document focuses on the Single Aspirated Air Temperature Sensors (SAATS) that will be used to develop temperature profiles. Temperature profiles will be ascertained by deploying SAATS at various heights on the core tower infrastructure and mobile platforms.

1.1 Purpose

This document details the algorithms used for creating NEON Level 1 data product for a single SAATS from Level 0 data, and ancillary data as defined in this document (such as calibration data), obtained via instrumental measurements made by the SAATS. It includes a detailed discussion of measurement theory and implementation, appropriate theoretical background, data product provenance, quality assurance and control methods used, approximations and/or assumptions made, and a detailed exposition of uncertainty resulting in a cumulative reported uncertainty for this product.

1.2 Scope

The theoretical background and entire algorithmic process used to derive Level 1 data from Level 0 data for the SAATS are described in this document. The temperature sensor employed is the Thermometrics Climate RTD 100 Ω Probe, which is housed in a Met One 076B fan aspirated radiation shield to reduce error from direct and indirect radiation. This document does not provide computational implementation details, except for cases where these stem directly from algorithmic choices explained here.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.005003	NEON Scientific Data Products Catalog
AD[03]	NEON.DOC.005004	NEON Level 1-3 Data Products Catalog
AD[04]	NEON.DOC.005005	NEON Level 0 Data Products Catalog
AD[05]	NEON.DOC.000782	ATBD QA/QC Data Consistency
AD[06]	NEON.DOC.011081	ATBD QA/QC plausibility tests
AD[07]	NEON.DOC.000783	ATBD De-spiking and time series analyses
AD[08]	NEON.DOC.000746	Evaluating Uncertainty (CVAL)
AD[09]	NEON.DOC.000302	C^3 Single Aspirated Air Temperature
AD[10]	NEON.DOC.000723	Triple Point Temperature Calibration Fixture
AD[11]	NEON.DOC.002002	ENG Master Location Sensor Matrix
AD[12]	NEON.DOC.000784	ATBD Profile Development
AD[13]	NEON.DOC.000785	TIS Level 1 Data Products Uncertainty Budget Estimation Plan
AD[14]	NEON.DOC.000751	CVAL Transfer of standard procedure
AD[15]	NEON.DOC.000747	Uncertainty Assessment Methodologies (CVAL)

2.2 Reference Documents

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms

2.3 Acronyms

Acronym	Explanation
ATBD	Algorithm Theoretical Basis Document
CVAL	NEON Calibration, Validation, and Audit Laboratory
DAS	Data Acquisition System
DP	Data Product
GRAPE	Grouped Remote Analog Peripheral Equipment
L0	Level 0
L1	Level 1
NOAA	National Oceanic Atmospheric Administration
PRT	Platinum Resistance Thermometer
RTD	Resistance Temperature Detectors
SAATS	Single Aspirated Air Temperature Sensor
UQ	Unquantifiable uncertainty
$\#_{CI}$	Value derived by CI given the equations within this document
$\#_{CVAL}$	Value provided by CVAL

2.4 Verb Convention

"Shall" is used whenever a specification expresses a provision that is binding. The verbs "should" and "may" express non-mandatory provisions. "Will" is used to express a declaration of purpose on the part of the design activity.

3 DATA PRODUCT DESCRIPTION

3.1 Variables Reported

Table 1 details the SAATS-related L1 DPs provided by the algorithms disclosed in this ATBD.

Table 1. List of SAATS-related L1 DPs that are produced in this ATBD.

Data product	**Averaging Period**	**Units**	**Data Product ID**
Temperature (T_{1min})	1-min	°C	NEON.DXX.XXX.DP1.00002.001.001.001.XXX.001
Minimum Temperature ($Tmin_{1min}$)	1-min	°C	NEON.DXX.XXX.DP1.00002.001.002.001.XXX.001
Maximum Temperature ($Tmax_{1min}$)	1-min	°C	NEON.DXX.XXX.DP1.00002.001.003.001.XXX.001
Variance ($T\sigma^2_{1min}$)	1-min	°C^2	NEON.DXX.XXX.DP1.00002.001.004.001.XXX.001
QA/QC Summary ($Qsum_{1min}$)	1-min	Text	NEON.DXX.XXX.DP1.00002.001.005.001.XXX.001
Temperature (T_{30min})	30-min	°C	NEON.DXX.XXX.DP1.00002.001.006.001.XXX.001
Minimum Temperature ($Tmin_{30min}$)	30-min	°C	NEON.DXX.XXX.DP1.00002.001.007.001.XXX.001
Maximum Temperature ($Tmax_{30min}$)	30-min	°C	NEON.DXX.XXX.DP1.00002.001.008.001.XXX.001
Variance ($T\sigma^2_{30min}$)	30-min	°C^2	NEON.DXX.XXX.DP1.00002.001.009.001.XXX.001
QA/QC Summary ($Qsum_{30min}$)	30-min	Text	NEON.DXX.XXX.DP1.00002.001.010.001.XXX.001

3.2 Input Dependencies

Table 2 details the SAATS-related L0 DPs used to produce L1 DPs in this ATBD.

Table 2. List of SAATS-related L0 DPs that are transformed into L1 DPs in this ATBD.

Data product	Sample Frequency	Units	Data Product ID
PRT resistance at temperature T (R_t)	1 Hz	Ω	NEON.DXX.XXX.DP0.00002.001.001.001.XXX.001
Flow Rate	TBD	TBD	TBD
Heater Status	TBD	Binary	NEON.DXX.XXX.DP0.00002.001.004.001.XXX.001

3.3 Product Instances

Multiple SAATSs will be deployed at tower sites. SAATS will be located on each boom arm below the top of the tower.

3.4 Temporal Resolution and Extent

One- and thirty-minute averages of temperature will be calculated to form L1 DPs.

3.5 Spatial Resolution and Extent

Each SAATS will represent the point at which it is placed on the tower infrastructure. Ultimately, a temperature profile will be developed for each tower site from the array of SAATSs on the tower (see AD[11] for detail on sensor placement for a specific core site, and AD[12] for description of the algorithms used for deriving this profile).

4 SCIENTIFIC CONTEXT

Temperature is one of the most fundamental physical measurements. It is a primary driving factor for countless physical, chemical, and biological processes. Temperature measurements will provide NEON with ancillary data for numerous other environmental measurements.

4.1 Theory of Measurement

Ultimately, temperature is derived from a PRT. Changes in the PRT resistance due to temperature are determined using a four-wire measurement. The four-wire measurement was chosen due to its decreased dependence

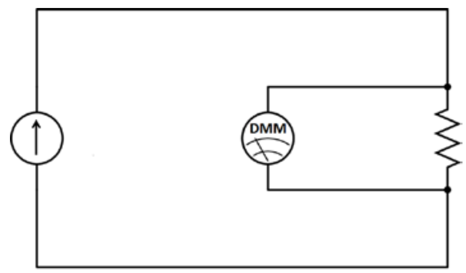

Figure 1. Four-wire measurement for PRT.

on cable length and resistors over the four-wire bridge method. Using a fixed current source the four-wire measurement detects a voltage drop across a resistor using a digital multi-meter (DMM) with a high impedance, shown in Figure 1. The voltage drop across the PRT is used, in conjunction with known current source, to calculate the PRT resistance. This measurement technique accomplished by a DMM (i.e. GRAPE) will acquire resistance for NEON operated PRTs.

4.2 Theory of Algorithm

The PRT is one of the most widely used RTD because platinum has the best linear relationship for changes in resistance to temperature over the greatest temperature range (−200 to 650 °C). Normally, when evaluating temperatures over the entire range of the PRT, the relationship between temperature and resistance for a PRT is expressed by two equations due a divergence from linearity. However, NEON is concerned with only a fraction of the PRT's functional range. Thus, within NEON's desired temperature range the relationship between temperature and resistance is simplified and temperature as a function of resistance is expressed by a single equation (AD[10]):

$$T = C_2 {R_T}^2 + C_1 R_T + C_0. \tag{1}$$

Where:

T = Temperature (°C)
C_0 = Calibration coefficients provided by CVAL (°C)
C_1 = Calibration coefficients provided by CVAL (°C/Ω)
C_2 = Calibration coefficients provided by CVAL (°C/Ω^2)
R_T = Resistance at temperature T (Ω)

After resistance is converted to temperature one-minute (T_{1min}) and thirty-minute (T_{30min}) averages of temperature (T) will be determined accordingly to create L1 DPs:

$$T_{1min} = \frac{1}{n}\sum_{i=x}^{n} T_i. \tag{2}$$

where, for each minute average, n is the number of measurements in the averaging period T and the averaging period is defined as $0 \le T < 60$ seconds.

and

$$T_{30min} = \frac{1}{n}\sum_{i=x}^{n} T_i. \tag{3}$$

where, for each thirty-minute average, n is the number of measurements in the averaging period T and averaging periods are defined as $0 \le T < 1800$ seconds and $1800 \le T < 3600$ seconds.

5 ALGORITHM IMPLEMENTATION

Data flow for signal processing of L1 DPs will be treated in the following order.

1. 1 Hz resistance data will be converted to temperature according to Eq. (1) using PRT calibration coefficients provided by CVAL.
2. QA/QC Plausibility tests will be applied to the data stream in accordance with AD[06]. The details are provided below.
3. Signal de-spiking and time series analysis will be applied to the data stream in accordance with AD[07].
4. One- and thirty-minute temperature averages will be calculated using Eq. (2) and (3).
5. Descriptive statistics, i.e. minimum, maximum, and variance, will be determined for both one- and thirty-minute averages.
6. QA/QC consistency tests will be applied to one- and thirty-minute averages in accordance with AD[05].
7. QA/QC Summary ($Qsum_{1min}$ and $Qsum_{30min}$) will be applied (flags are defined below).

<u>**QA/QC Procedure**</u>:

1. **Plausibility Tests** AD[06]
   a. <u>Range Test</u> – Maximum and minimum values for the range test will be provided by FIU and maintained in the CI data store. This test will be applied to every L0 datum and associated pass/fail flags will be generated.
   b. <u>Sigma Test (σ)</u> – This test will be applied to the L0 time series in 60 second increments. Time segments and thresholds will be provided by FIU and maintained in the CI data store. The sigma pass/fail flag will be applied to every datum in the window.
   c. <u>Delta Test (δ)</u> – This test will be applied to the L0 time series in 60 second increments. Time segments and thresholds will be provided by FIU and maintained in the CI data store. The delta pass/fail flag will be applied to every datum in the window.
   d. <u>Step Test</u> – This test will be applied to every L0 datum and associated pass/fail flags will be generated. Thresholds will be provided by FIU and maintained in the CI data store.
   e. <u>Gap Test</u> – Will not be computed for temperature.
   f. <u>Null Test</u> – Missing data points are identified by the null test flagged accordingly.

2. **Sensor Test** – Sensor flags (i.e., flow rate and heater) are derived from L0 data products identified in the C^3 document (AD[09]). Any L0 DP (i.e., 1 Hz data) to which the heater and flow rate flags have been applied will not be used to compute L1 DPs. These flags will be combined with the other QA/QC flags and included in the L1 QA/QC summary (details below).

a. Heater:

$$f_H = \begin{cases} 1 \ if \quad t_i < t < t_i + (1.5 * t_h) \\ 0 \ otherwise \end{cases}$$

Where: t = Current time
t_i = Initial time that the heater turned on
t_h = Amount of time that the heater stays on for one cycle

The heater flag configuration tests for whether the heater is on or was on during the preceding time interval. Data will continue to be flagged after the heater shuts off for half of the time the heater was operating, to allow for heat to dissipate around the aspirated shield. The t_h time is described in AD[09] and kept in the CI data store..

b. Flow Rate:

$$f_F = \begin{cases} 1 \ if \quad F < F_{min} \\ 0 \ otherwise \end{cases}$$

Where: F = Flow rate
F_{min} = Minimum flow rate

The flow rate flag indicates whether the sensor is adequately aspirated. F_{min} is a site specific variable that is described in AD[09], provided by ENG, and kept in the CI data store.

3. **Signal De-spiking and Time Series Analysis** – The de-spiking QA/QC routine will be run on defined time segments of data, as specified by FIU and maintained in the CI data store. Utilizing the median absolute deviation for a segment of data, the routine will identify and disregard large spikes from the time series. For data values that are "de-spiked" a de-spiking flag will be applied according to AD[07].

4. **Consistency Analysis** – A QA/QC flag for data consistency (f_V) will be applied according to the consistency analysis outlined in AD[05], and a pass/fail flag will be generated to reflect this activity. To evaluate temperature for consistency, L1 temperature from a given SAATS will first be compared to the SAATS above it on the tower infrastructure. If a difference between the two temperature measurements is less than the defined limits, provided by FIU and maintained in

the CI data store, then the sensor will have passed the consistency analysis. Alternatively, a temperature difference between the SAATS outside the defined limits will result in a failed test. A failed test from the above sensor will result in the SAATS being compared to the SAATS below it; if this too results in a failed test then the SAATS will have failed the consistency test and be flagged as such. If the SAATS fails the first test but passes the second then it will have passed the consistency test. This structure helps to ensures that non-functional sensors (e.g. sensors that are faulty or down for service) do not bias the test, since a resulting failed test will allow the sensor to be compared to the one below it. Accordingly, the SAATS on the bottom of the tower will only be compared to the SAATS above it and the uppermost SAATS will first be compared to the TRAATS and then to the SAATS below it. L1 DPs that fail the consistency analysis will continue to be reported, but will have an associated failed flag that will be include in the QA/QC summary.

Notes:

1. SAATS L1 DP will have an associated QA/QC summary DP ($Qsum_{1min}$ and $Qsum_{30min}$) that summarizes any flagged data that went into the computation of the L1 DP. This summary will offer transparency to the data user, who will be able to determine whether any of the DPs used generate a specific L1 DP were flagged (e.g., plausibility flags and details on the number of points flagged in the L0 data).
2. A datum flagged by any of the following eight flags, f_R, f_σ, f_δ, f_S, f_N, f_D, f_H, and f_F, as a result of plausibility, de-spiking, and or sensor tests, will not be used to compute the L1 DP. If the number of data points flagged by these tests exceeds 20 % of the data for an averaging period, i.e. 12 points for T_{1min} or 360 points for T_{30min}, that time period will not be calculated due to insufficient reliable data and be flagged as $f_\varnothing$ to denote this. Note that a datum can only contribute to this total once, i.e. multiple flags on the same datum do not contribute more than once to the percentage of flagged data. Likewise, if the number of points flagged as null, f_N, exceeds 20% for an averaging period it will not be computed due to too many missing data points.
3. The 11 flags that may be associated with SAATS measurements, as well as information maintained in the CI data store can be found below in Tables 3 and 4.

Table 3. Flags associated with SAATS measurements.

Tests	Flags
Range	f_R
Sigma (σ)	f_α
Delta (δ)	f_δ
Step	f_S
Null	f_N
Signal Despiking and Time Series Analysis	f_D, f_o
Sensor Test (Heater Flag) AD[09]	f_H, f_F
Consistency Analysis	f_V
Insufficient Reliable Data	$f_\varnothing$

Table 4. Information maintained in the CI data store for SAATS.

Tests/Values	CI Data Store Contents
Range	Minimum and maximum values
Sigma (σ)	Time segments and threshold values
Delta (δ)	Time segment and threshold values
Step	Threshold values
Null	Test limit
Signal Despiking and Time Series Analysis	Time segments and threshold values
Calibration	CVAL sensor specific calibration coefficients
Uncertainty	CVAL and ENG uncertainty
Sensor Test	F_{min} and t_h as described in AD[09]
Consistency Analysis	Test limits
Insufficient Reliable Data	Time segment and threshold values

6 UNCERTAINTY

Uncertainty of measurement is inevitable (ISO 1995; Taylor 1997). It is imperative that uncertainties are identified and quantified to determine statistical interpretations about mean quantity and variance structure; both are needed to construct higher level data products (i.e., L1 DP, etc.) and modeled processes. This portion of the document serves to identify, evaluate, and quantify sources of uncertainty relating to L1 DPs associated with SAATS. It is a reflection of the information described in AD[13], and is explicitly described for SAATS L1 DPs in the following sections.

6.1 Uncertainty of Temperature Measurements

Uncertainty of the SAATS assembly is discussed in this section. Sources of uncertainties include those arising from the calibration procedure, PRT sensor, heater, aspiration, DAS/GRAPE conversion to resistance and algorithms (Figure 2).

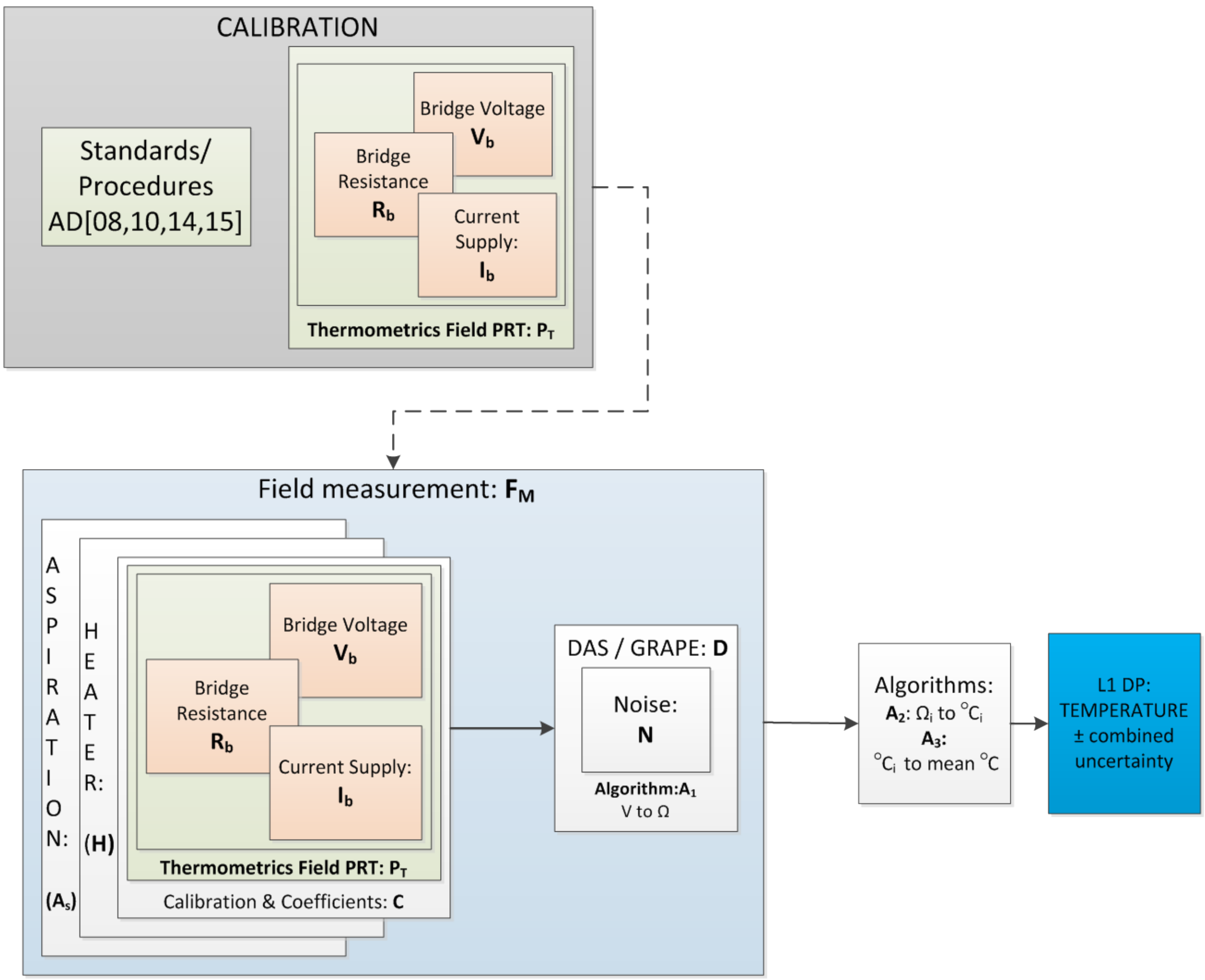

Figure 2: Displays the data flow and associated uncertainties of L1 temperature DPs. Salmon colored boxes represent direct measurement of temperature based on the theory of PRT resistance. For a detailed explanation of the PRT calibration procedures, please refer to AD[08,10,14,15].

6.1.1 Calibration:

Uncertainties associated with the calibration process are combined into an individual, standard uncertainty $u(T_{CAL})$ by CVAL. It is a constant value that will be applied to all PRT measurements (that is, it does not vary with any specific sensor, DAS component, etc.). Please refer to AD[08] for the value of this individual standard uncertainty

$$u(T_{CAL}) = \pm \#_{CVAL} \,℃ \tag{4}$$

6.1.2 Field Measurements

As mentioned before, SAATS measurements throughout NEON's Observatory will be subject to additional uncertainties (i.e., aspiration, etc.) other than those solely associated with the PRT measurement.

6.1.2.1 DAS/GRAPE

Most errors for *each* field PRT will be corrected during the calibration process. Despite this, 'noise' and data conversion within the DAS/GRAPE adds additional uncertainties to the PRT measurement. Nominally, the DAS/GRAPE has an uncertainty of $\pm 20\, m\Omega$. This is a reflection of the maximum allowable uncertainty arising from conversion of V to Ω within the DAS/GRAPE (Section 4.1), as well as 'noise' of the measurement. CVAL will provide an exact value ($\#_{CVAL}$) for uncertainty based on internal tests conducted at NEON. Please refer to AD[08] to obtain the exact value of this individual, standard uncertainty.

$$u(D) = \pm \#_{CVAL}\, \Omega \tag{5}$$

6.1.2.2 Heater

Most of an aspirated shield's exterior is wrapped in heating material. This heater will be turned on during times when ice buildup causes a potential threat to the aspiration of the shield. When the heater is on, it is hypothesized that some of the thermal energy will conduct through the aluminum shield, thus altering the internal temperature of the shield and result in large measurement errors.

At this time, the extent to which the heater will affect the measurement is unclear. Because of this, any measurements recorded during times of heating, and for a specified time after the heater is turned off (refer to Section 5) carries a great deal of uncertainty, and the data will be considered *void* (i.e. will not be used to calculate a L1 DP). This is an example of an uncertainty that can be identified, but cannot be quantified at this time.

$$u(H) \approx UQ: data\ not\ used\ to\ calculate\ L1\ DPs \quad (6)$$

6.1.2.3 Aspiration

Met-One (1997) states temperature *error* of their 076B fan-aspirated shield to be $< 0.05\ °F = 0.027778$ ℃, assuming flow rate is sufficient ($\sim 500\ F^3\ min^{-1} \approx 0.236\ m^3\ s^{-1}$). When the flow rate drops below this threshold, the temperature errors increase due to the effects of direct and indirect radiation as stagnant air accumulates within the shield. Previous studies that focused on the temperature errors associated with passive multi-plate radiation shields (non-fan-forced aspiration), showed that air temperature errors increased as solar radiation increased and aspiration rate decreased (e.g., Brock *et al*. 1995; Lin *et al*. 2000). Brock *et al*. (1995) note that when insolation rose above 700 W m^2, and wind speed fell below 2 m s^{-1}, temperature errors were > 2℃. Richardson *et al*. (1999) demonstrated that errors due to poor natural aspiration resulting from low wind speeds (as shown in Brock et al. 1995) can be lessened via fan-forced aspiration, but cannot be completely diminished especially during daytime. Although Met One's 076B is fan-aspirated, it offers minimal natural aspiration given its design. This method is more efficient than the standard natural aspirated shields; yet large temperature errors may be possible due to insufficient aspiration if the fan slows down or stops working altogether. Temperature errors larger than those discussed by the previously cited authors may be possible based on the lack of natural ventilation of Met One's 076B fan-aspirated shield. However, the magnitude of these errors is currently unknown. Thus, at this time, we cannot confidently quantify the uncertainty that is added to the temperature measurements when the aspiration within the shield is well below its nominal flow rate. During these times, data will be void and will not be used to calculate L1 DPs. Only when the flow rate is sufficient (i.e. $\approx 0.236\ \mathrm{m^3\ s^{-1}}$) will data be used to calculate L1 DPs:

$$u(A_s) = \pm\ 0.02778\ ℃\ | \quad If\ flow\ rate\ \approx 0.236\ \mathrm{m^3\ s^{-1}} \quad (7)$$

$$u(A_s) \approx UQ\ | \quad If\ flow\ rate \ll 0.236\ \mathrm{m^3\ s^{-1}}: data\ not\ used\ to\ calculate\ L1\ DPs$$

6.1.3 Algorithms

Three algorithms are utilized when converting raw observational data to L1 DPs. Uncertainties from the first algorithm (Eq.) are accounted for by the previously mentioned $u(T_{CAL})$ and $u(R_T)$. Uncertainties arise due to the introduction of calibration coefficients ($C_{0\text{--}2}$) when converting raw Ω data to temperature °C (Eq. (1)). Although each coefficient has its own level of uncertainty, we can assume that uncertainties of each coefficient are equal because of the near linearity of the polynomial used for fitting the raw data. To account for the uncertainty of the coefficients, the partial derivative, also known as the sensitivity coefficient with respect to R_T is given:

$$\frac{\partial T}{\partial R_T} = 2C_2(R_T) + C_1 \tag{8}$$

Although errors of each field PRT (R_T) will be corrected during the calibration process, 'noise' and uncertainties of the DAS/GRAPE will be present in the field. Thus, the uncertainty value of $u(D)$, can be substituted into Eq. in place of $u(R_T)$;

$$u(R_T) = u(D) = \pm \#_{CVAL}\ \Omega \tag{9}$$

The partial uncertainty of the L1 SAATS DP with respect to noise is then:

$$u_{R_T}(T_{L1}) = |2C_2(R_T) + C_1|u(R_T) \tag{10}$$

The third algorithm (Eq. (2) or (3) depending on the temporal period) is an averaging algorithm and any uncertainty related to it is due to round-off errors. Algorithms used to average data should not produce additional uncertainty given the fact that a majority of significant figures from raw data will be preserved during conversions from raw to L1 data. Thus, the uncertainty produced from round off errors will be smaller than the sensitivity of the sensor, and is insignificant.

6.1.4 Natural Variation

The final uncertainty component of the L1 DP is that of natural variation of the mean value. When we average the data to generate a L1 DP, the estimated standard deviation of the mean will be computed and exhibit the uncertainty of the mean temperature value for the specified time period:

$$u(\bar{T}) = \frac{s(T_k)}{\sqrt{n}} = \pm \#_{CI}\ ^{\circ}\mathrm{C} \tag{11}$$

where $s(T_k)$ is the experimental standard deviation and n is the number of observations made over a given time period.

6.2 Combined Uncertainty

As mentioned before, the uncertainties associated with the heater and poor aspiration cannot be quantified. Thus, ***all data will be void,*** and a L1 DP will not be calculated when the heater is on or if the flow rate within the shield is insufficient.

$$u_c(T_{L1}) = \left(u^2{}_{R_T}(T_{L1}) + u^2(T_{CAL}) + u(A_s)^2 + u(\bar{T})^2\right)^{\frac{1}{2}} = \pm \#_{CI}\ ^{\circ}\mathrm{C} \tag{12}$$

6.3 Expanded Uncertainty

The expanded uncertainty for L1 SAATS DPs can be derived with the following equations:

$$V_{eff}(T_{L1}) = \frac{[u_c(T_{L1})]^4}{\frac{u^4{}_{R_T}(T_{L1})}{V_{R_T}} + \frac{u^4(T_{CAL})}{V_{T_{CAL}}} + \frac{u^4(A_s)}{V_{A_s}} + \frac{u^4(\bar{T})}{V_{\bar{T}}}} = \#_{CI} \tag{13}$$

$V_{R_T}, and\ V_{\bar{T}}$ spawn from Type A analyses, and their values will be $n-1$, where n is the number of observations made during the averaging period; $V_{T_{CAL}}$, also a Type A evaluation, will be based on the number of tests run by CVAL when calibrating the PRTs (refer to AD[08]). The value of V_{A_s} will always be 100 (refer to AD[13]), as its uncertainty value is obtained from the manufacturers specifications and is considered a Type B evaluation.

The expanded uncertainty is then:

$$U_{95}(T_{L1}) = k_{95} u_c(T_{L1}) = \pm \#_{CI}\ ^\circ\mathrm{C} \tag{14}$$

Where k_{95} is the coverage factor obtained from:

- Table 4 from AD[13]
- Resulting effective degrees of freedom $V_{eff}(T_{L1})$ from Eq. (13).

6.4 Uncertainty Budget

The uncertainty budget is an outline of all sources of uncertainty, means by which these uncertainties are derived, and the resulting combined and expanded uncertainties. It is provided here to display specific, individual sources of uncertainty that propagate into a combined and expanded uncertainty. Individual uncertainty values denoted in Table 2 are either provided here (in this document) or will be provided by other NEON teams (e.g. CVAL). Each L1 DP will be presented twice, once accompanied by a value of combined uncertainty, and again with an expanded uncertainty value. The coverage factor should always accompany the expanded uncertainty value (ISO 1995). Effective degrees of freedom for each computed L1 DP will be stored in the CI data store, but not displayed with the L1 DP.

Table 5. Uncertainty budget for SAATS L1 DPs.

Source of uncertainty	Individual, standard uncertainty component u(X$_i$)	Type of evaluation	Value of individual, standard uncertainty [°C]	$c_i \equiv \frac{\partial f}{\partial x_i}$	$u_i(Y) \equiv \lvert c_i \rvert u(x_i)$ [°C]
Calibration	$u(T_{CAL})$	A	Eq. (4)	1	Eq. (4)
Noise (DAS/GRAPE)	$u(R_T)$	A	Eq. (5) [Ω]	Eq. (8)	Eq. (10)
Aspiration	$u(A_s)$	B[1]	0.02778	1	0.02778
Natural Variation	$u(\bar{T})$	A	Eq. (11)	1	Eq. (11)
					$u_c(T_{L1})$: Eq. (12)
					$T_{L1} = L1\ DP \pm u_c(T_{L1})$°C
					$v_{eff}(T_{L1})$: Eq. (13)
					k_{95}: $v_{eff}(T_{L1})$ & Table 4 of AD[13]
					$U_{95}(T_{L1})$: Eq. (14)
					$T_{L1_{95}} = L1\ DP \pm U_{95}(T_{L1})$°C

[1]Met One (1997)

7 FUTURE PLANS AND MODIFICATIONS

Future system flags may be incorporated into the data stream and included in the QA/QC summary DP ($Qsum_{1min}$ and $Qsum_{30min}$) that summarizes any flagged data that went into the computation of the L1 DP.

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