Calibration Fixture and Sensor Uncertainty Analysis

CVAL 2014 Uncertainty Manual

PREPARED BY	ORGANIZATION	DATE
Janae Csavina	CVAL	11/30/2015

APPROVALS	ORGANIZATION	APPROVAL DATE
Kathy Kirby	PMO	11/23/2015

RELEASED BY	ORGANIZATION	RELEASE DATE
Anne Balsley	CM	11/30/2015

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Change Record

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 DESCRIPTION

This document describes the general philosophy and approach to quantify uncertainty for all calibration/validation fixtures and sensors at the NEON Calibration, Validation and Audit Laboratory (CVAL).

1.1 Purpose

Uncertainty of measurement is inevitable (ISO 1995; Taylor 1997) and therefore is imperative to identify and quantify. Quantification is completed in order to determine statistical interpretations about mean quantity and variance structure; both are needed to construct higher data products and modeled processes. This document serves as a guideline to identify, evaluate, and quantify sources of uncertainty relating to a specific calibration fixture and sensor. Validation processes are also described here.

1.2 Scope

This manual aims to provide all uncertainty assessment information for the calibration methods and sensors for calendar YR2014.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

AD[01]	DOORS Database CV Module
AD[02]	NEON.DOC.002652NEON Level 1, Level 2 and Level 3 Data Products Catalog
AD[03]	NEON.DOC.000785TIS Level 1 Data Products Uncertainty Budget Estimation Plan
AD[04]	NEON.DOC.000257 Tier 3 – CVAL Requirements Module
AD[05]	NEON.DOC.000267 Tier 4 – CVAL Requirements Module
AD[06]	NEON.DOC.000508 Tier 5 – CVAL Requirements Module

2.2 Reference Documents

RD[01]	NEON.MGMT.NPR.000008.GEN NEON Glossary of Abbreviations
RD[02]	NEON.DOC.000927 Calibration and Sensor Uncertainty Values
RD[03]	NEON.DOC.001641 CVAL QA/QC Manual
RD[04]	NEON.DOC.000745 L1R300 Cimel Sunphotometer Calibration Fixture Manual (Indoor)
RD[05]	NEON.DOC.000801 L2R300 Cimel Sunphotometer Calibration Fixture Manual (Outdoor)
RD[06]	NEON.DOC.000902 L2B100 WOII 2D Anemometer Validation Fixture Manual
RD[07]	NEON.DOC.002475 L2B200 CSAT 3D Wind Validation
RD[08]	NEON.DOC.001084 L1W300 Sentek Soil Moisture Calibration Fixture Manual

RD[09]	NEON.DOC.001216 L1A200 Nutrient Analyzer Calibration Fixture Manual
RD[10]	NEON.DOC.002429 L1J100 Dust Track Calibration Fixture Manual
RD[11]	NEON.DOC.000723 L1T200 PRT Calibration Fixture Manual
RD[12]	NEON.DOC.000744 L1R600 IR Calibration Fixture Manual
RD[13]	NEON.DOC.000735 L1E100 Barometric Pressure Calibration Fixture Manual
RD[14]	NEON.DOC.000802 L2R200 NR01 Pyrgeometer Radiation Calibration Fixture Manual
RD[15]	NEON.DOC.002213 L2R700 NR01 Pyranometer Radiation Calibration Fixture Manual
RD[16]	NEON.DOC.000800 L2R800 CMP22 Pyranometer CMP22 Calibration Fixture Manual
RD[17]	NEON.DOC.000794 L2R400-500 SPN1 Sunshine Pyranometer Calibration Fixture Manual
RD[18]	NEON.DOC.000752 L2R600 Line Quanta PAR Calibration Fixture
RD[19]	NEON.DOC.000742 L1R100 PAR Primary Calibration Fixture
RD[20]	NEON.DOC.000743 L1R200 PAR Secondary Calibration Fixture
RD[21]	NEON.DOC.000748 L2R100 PAR Outdoor Validation Fixture
RD[22]	NEON.DOC.000754 L1D100 DAS (Data Acquisition System) - Grape Calibration Fixture
RD[23]	NEON.DOC.001066 L1W100 Relative Humidity Calibration Fixture Manual
RD[24]	NEON.DOC.002556 Aquatic Pressure Fixture L1A3000000 CVAL Fixture Manual
RD[25]	NEON.DOC.001276 Aquatic Temperature Fixture L1A4000000 CVAL Fixture Manual
RD[26]	NEON.DOC.002557 Aquatic Troll Conductivity Fixture L1F1000000 CVAL Fixture Manual
RD[27]	NEON.DOC.001212 L1P200 Tipping Bucket Calibration Fixture Manual
RD[28]	NEON.DOC.002422 L1W200 Water Isotopes Picarro Calibration Fixture Manual
RD[29]	NEON.DOC.001215 L1F200-600 Sonde Solutions Calibration Fixture Manual
RD[30]	NEON.DOC.001214 L1G300 Soil CO2 Calibration Fixture Manual
RD[31]	NEON.DOC.002367 L1J200 HiVol Particulate Sampler Calibration Fixture Manual
RD[32]	NEON.DOC.002543 L1J300 HiVol Orifice Plate Calibration Fixture Manual
RD[33]	NEON.DOC.002421 L1G500 Carbon Isotopes Calibration Fixture Manual
RD[34]	NEON.DOC.002474 L1G200 IRGA Calibration Fixture Manual
RD[35]	NEON.DOC.001213 L1P100 Primary Rain Gauge Calibration Fixture Manual

2.3 Acronyms

ATBD: Algorithm Theoretical Basis Document
BIPM: Bureau International des Poids et Mesures
CI: Cyber Infrastructure
CVAL: Calibration, Validation and Audit Laboratory
DAS: Data Acquisition System
DMM: Digital Multimeter
GUM: Guide to the expression of uncertainty in measurement
ICD: Interface Control Document
ISO: International Organization for Standardization
IEC: International Electrotechnical Commission
JCGM: Joint Committee for Guides in Metrology
MUX: Multiplexer
OIML: International Organization of Legal Metrology
SPRT: Standard Platinum Resistance Thermometer

UUT: Unit Under Test
XML: Extensible Markup Language

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 EVALUATING UNCERTAINTY

3.1 Overview

The approach to expressing uncertainty was developed utilizing *JCGM 100:2008 Evaluation of measurement data – Guide to the expression of uncertainty in measurement (GUM).* GUM provides general rules for evaluating and expressing uncertainty in measurement that are intended to be applicable to a broad spectrum of measurements. GUM was prepared by individuals nominated by the Bureau International des Poids et Mesures (BIPM), the International Electrotechnical Commission (IEC), the International Organization for Standardization (ISO), and the International Organization of Legal Metrology (OIML). It is, at present, the most complete reference on general application to expressing measurement uncertainty, and its development is giving further impetus to the worldwide adoption of that approach. GUM may be consulted for additional details to those provided below.

Uncertainty is defined as a parameter, associated with the result of a measurement, which characterizes the dispersion of the values that could reasonably be attributed to the measurand (particular quantity subject to measurement). Therefore, the result is only an estimate of the value of the measurement because of the uncertainty arising from random effects and from imperfect correction of the result for systematic effects. GUM describes two methods for quantifying uncertainty: Type A are those which are evaluated by statistical methods and Type B are those which are evaluated by other means. Generally, Type A uncertainty is evaluated by experimental variance of independent observations which differ in value because of random variations in the influence quantities and random effects. For an uncertainty component obtained from a Type B evaluation, estimates are obtained using available published knowledge such as manufacturer's specification, calibration certificates, reference data taken from handbooks, etc.

As an example of a Type A evaluation, consider an input quantity X_i whose value is estimated from n independent observations $X_{i,k}$ of X_i obtained under the same conditions of measurement. In this case the input estimate x_i is usually the sample mean as described in Equation 1,

$$x_i = \bar{X}_i = \frac{1}{n}\sum_{k=1}^{n} X_{i,k} \tag{1}$$

and the standard uncertainty $u(x_i)$ to be associated with x_i is the estimated standard deviation of the mean as shown in Equation 2.

$$u(x_i) = s(\bar{X}_i) = \left[\frac{\sum_{k=1}^{n}(X_{i,k}-\bar{X}_i)^2}{n(n-1)}\right]^{\frac{1}{2}} = \frac{s(X_i)}{(n)^{1/2}} \quad (2)$$

When uncertainty is to be estimated where a sample mean is not used, such as when determining reproducibility of a calibration with varying conditions, then standard deviation (Equation 3) best describes the contributing uncertainty related to the variations.

$$u(X_i) = s(X_i) = \left[\frac{\sum_{k=1}^{n}(X_{i,k}-\bar{X}_i)^2}{(n-1)}\right]^{\frac{1}{2}} \quad (3)$$

From Type A and/or Type B evaluation, individual standard uncertainties are combined to represent the total estimated standard deviation of the result (or combined standard uncertainty of a measurement result, u_c). The combined standard uncertainty of the measurement result y, designated by $u_c(y)$ and taken to represent the estimated standard deviation of the result, is the positive square root of the estimated variance $u_c^2(y)$ obtained from:

$$u_c^2(y) = \sum_{i=1}^{n}\left(\frac{\partial}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(\frac{\partial}{\partial x_i}\right)\left(\frac{\partial}{\partial x_j}\right)u(x_i, x_j) \quad (4)$$

Equation 4 is based on a first-order Taylor series approximation of the measurement equation $Y = f(X_1, X_2, \ldots, X_N)$ and is conveniently referred to as the law of propagation of uncertainty. The partial derivatives of f with respect to the X_i (often referred to as sensitivity coefficients) are equal to the partial derivatives of f with respect to the X_i evaluated at $X_i = x_i$; $u(x_i)$ is the standard uncertainty associated with the input estimate x_i; and $u(x_i, x_j)$ is the estimated covariance associated with x_i and x_j.

Equation (4) often reduces to a simple form in cases of practical interest. For example, if the input estimates x_i of the input quantities X_i can be assumed to be uncorrelated, then the second term vanishes. However, it should be noted that when the nonlinearity of f is significant, higher order terms of the Taylor series expansion should be included.

Further, as shown in Equation 5, the combined variance $u_c^2(y)$ (with combined uncertainty being $u_c(y)$) can be viewed as a sum of variance components $u_i^2(y)$ where each component represents the estimated variance in y attributable to input estimate x_i.

$$u_c(y) = \left[\sum_{i=1}^{n} u_i^2(y)\right]^{\frac{1}{2}} \quad (5)$$

In Equation 5, combined uncertainty is not quantified in relative terms. This allows $u_c(y)$ to be in the same units as y. Depending on the application, one method may be more advantageous than the other. Often, if the uncertainty scales with the measurement, the use of a relative uncertainty is a more practical representation in % of reading:

$$u_{c,r}(y) = \frac{u_c(y)}{|y|} \tag{6}$$

Here $u_{c,r}(y)$ is the relative combined standard uncertainty of y and $|y|$ is the absolute value of y where it is assumed that y is not equal to zero.

If the probability distribution characterized by the measurement result y is approximately normal (Gaussian), then $u_c(y)$ is a reliable estimate of the standard deviation of y. Thus, the interval $y - u_c(y)$ to $y + u_c(y)$ is expected to encompass approximately 68% of the distribution of values that could reasonably be attributed to the value of the quantity Y of which y is an estimate. This implies that it is believed with an approximate level of confidence of 68% that Y is greater than or equal to $y - u_c(y)$, and is less than or equal to $y + u_c(y)$, which is commonly written as $Y= y \pm u_c(y)$. The measurement errors are assumed to follow a normal distribution and as such provide a means for validating the specification of the measurand. Significant deviation from normality typically indicates the existence of unaccounted for sources of uncertainty.

Because a level of confidence of 68% is below industry standard, the uncertainty can be "expanded" by multiplying $u_{c,r}(y)$ by a coverage factor, k_p.

$$U_p = k_p\, u_{c,r}(y) \tag{7}$$

This expanded uncertainty, U_p, at NEON should represent a confidence level of 95%. Therefore, $p=95$ and assuming a normal distribution, $k_{95}=1.96$. However, to obtain a better approximation than simply using a value of k_p from the normal distribution, the distribution of the variable may be approximated by a t-distribution with an effective degrees of freedom v_{eff} obtained from the Welch-Satterthwaite formula:

$$v_e = \frac{u_c^4(y)}{\sum_{i=1}^{n} \frac{u_i^4(y)}{v_i}} \tag{8}$$

The coverage factor then becomes $k_p = t_p(v_{eff})$ and $t_p(v_{eff})$ is obtained from Table G.2 in the *GUM.* If the degrees of freedom is not represented in the table (i.e. not a whole number), the value may be interpolated. The degrees of freedom v is equal to n-1 for a single quantity estimated by the arithmetic mean of n independent observations. If n independent observations are used to determine both the slope and intercept of a straight line by the method of least squares, the degrees of freedom of their respective standard uncertainties is $v=n-2$. For a least-squares fit of m parameters to n data points, the degrees of freedom of the standard uncertainty of each parameter is $v=n-m$.

For Type B evaluation of standard uncertainty, the degrees of freedom is a subjective quantity whose value is obtained by scientific judgment based on the pool of available information. In general, a high level of confidence can be assumed for published information, and therefore, assuming 100 as a general degrees of freedom may be a conservative estimate. However, if little information is known about the source of the Type B uncertainty, other approaches such as taking 90% of the resolution of the data averaged for a given data point may be used. Methods for arriving at the quantity will vary on a case by case basis depending on the amount of information and level of confidence in the manufacturer.

3.2 Evaluating Fixtures and Sensors

Each fixture and a population of sensors will be evaluated for uncertainty on an annual basis. The aim of this evaluation will be to provide a quality metric for the field measurements, monitor sensor health and provide drift analysis of the calibration and/or sensor. While each evaluation will be unique to the components expected to cause uncertainty in the calibrations such as ambient conditions, multiple operators, etc., the uncertainty components will remain the same, are outlined below in Sections 3.2.1 through 3.2.5, and are illustrated in Figure 1. When Type A evaluations are used, the maximum uncertainty found for the population being evaluated should be used as a conservative approach to uncertainty assessment. Additionally, where possible, the full range of expected measurements should be included in the evaluation; again, taking the maximum approach. Since CVAL reports one value for uncertainty across the range of operating conditions and the population of sensors, the uncertainty terms are calculated for a given sensor along the sensor's range and the maximum value amongst the sample of sensors and range is taken.

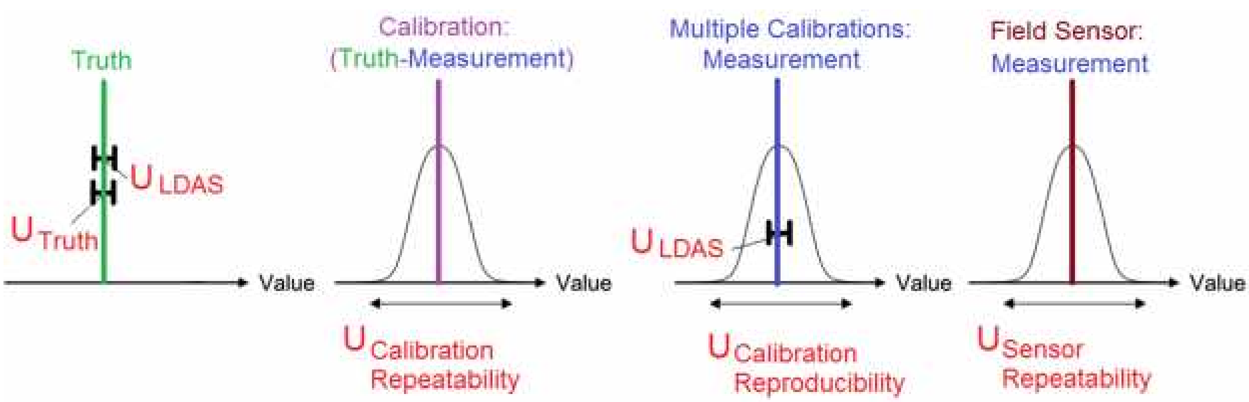

Figure 1: Illustration of the general terms (U_x) quantified during an uncertainty assessment.

Annually derived values are maintained in NEON.DOC.000927 which is a spreadsheet for Calibration Uncertainty Values. Once a new document is created containing new evaluated values, the document numbers NEON.DOC.000927 and NEON.DOC.000746 will remain for the spreadsheet and evaluation details (this document) of the current calendar year, respectively, and previous year's documents will become new document numbers for archiving purposes. A running summary of previous years' document numbers will be maintained in NEON.DOC.000746. This allows for both internal and external users to easily compare values quantified in different operating years and compare to automated uncertainties calculated for data products. In some cases, such as calibration repeatability and sensor repeatability, the uncertainties will be used in automated QA/QC for the calibration fixtures. For more information on this, see NEON.DOC.001641 the CVAL QA/QC Manual.

3.2.1 Truth

Truth represents the uncertainty related to the standard used in the calibration. The standard is considered the “truth” to which the sensor (or UUT, unit under test) is being calibrated. Type B assessment is typically used for estimating this uncertainty which comes from calibration certifications of the standard. In some cases, the manufacturer/calibration institute will provide a tolerance or accuracy estimate. When tolerance (t) is given, a rectangular (uniform) distribution is assumed and Equation 9 describes the appropriate transformation for calculation of the uncertainty. The term “accuracy” (a) is subject to different interpretations; thus, every attempt will be made to clarify a particular manufacturer’s meaning. When this information is unavailable, it will be assumed that either accuracy describes the full possible distribution of the measurements (in which case Eqn. 10a applies) or that accuracy describes a typical deviation (in which case Eqn. 10b applies).

$$u(x_i) = \frac{t}{\sqrt{3}} \tag{9}$$

$$u(x_i) = \frac{a}{3} \tag{10a}$$

$$u(x_i) = a \tag{10b}$$

3.2.2 Calibration Repeatability

Precision is often used to describe this term, but to remove ambiguity; repeatability will be used when described in uncertainty assessment. Uncertainty related to the repeatability of the calibration utilizes the UUT measurement (X_i) and standard (or truth) measurement (Y_i) with Type A evaluation estimated by Equation 11.

$$u(X_i) = s(X_i) = \left[\frac{\sum_{k=1}^{n}(X_{i,k}-Y_{i,k})^2}{(n-1)}\right]^{\frac{1}{2}} \tag{11}$$

This calculation was developed to better represent the repeatability of the calibration. In a sense, it is normalizing the data to the truth to remove fluctuations that may be occurring in the calibration fixture as explained below:

A single calibration is fit so that the standard deviation of the differences $\sigma_d = \sqrt{\frac{\sum(x_i-s_i)^2}{n-1}}$ is minimized where x_i is the UUT’s measurement and s_i is the corresponding standard measurement. Note: it’s actually fit so that $\sqrt{\frac{\sum(\bar{x}-\bar{s})^2}{n-1}}$ is minimized but the fit will be the same for equal sample sizes.

Also note that: $\sum(x_i - s_i)^2 = \sum(x_i - \bar{x})^2 + \sum(s_i - \bar{s})^2$ so that when we estimate $\sqrt{\frac{\sum(x_i-s_i)^2}{n-1}}$ we are actually measuring variability of x’s and the variability of standard under repeatable conditions.

3.2.3 Sensor Repeatability

While the repeatability of the calibration is captured in the term described in Section 3.2.2, it does separate out the sensor repeatability which is important for an individual field measurement. This term is included for level zero uncertainty of NEON reported data as it represents the spread that a measurement could have under identical conditions. Sensor repeatability, however, is not included in the combined calibration uncertainty as is inherent to the calibration repeatability term.

3.2.4 Calibration Reproducibility

Variations that could occur for a calibration should be evaluated using the Type A approach and estimated by standard deviation (Equation 3). Here, the conditions to vary will be sensor/fixture specific. At minimum, the calibration should be reproduced ~10 times for a single sensor for fixture limitations. Ideally, multiple sensors will be tested for worst case of a population and these sensor calibrations will be evaluated under multiple operators, ambient conditions, and seasonality. However, this year's evaluation met only the minimum for some fixtures due to sensor quantity limitations and meeting deadlines. If conditions could not be varied because of these or other limitations, the unquantified uncertainty shall be noted.

3.2.5 Laboratory Data Acquisition System (LDAS)

Uncertainty related to the data acquisition system used in the CVAL lab. This uncertainty is typically estimated by a Type B evaluation using methods similar to the Truth analysis. In some cases, the data acquisition system will include a multiplexer (mux) box. In this case, the truth should be considered the raw reading of a precision resistor or voltage signal without the mux in place. Calculate the calibration repeatability and reproducibility of a precision signal from the mux box and add this as a term for uncertainty. Additionally, in some cases, the DAS uncertainty will need to be added twice if the truth has a signal interpreted to a reading. As mentioned earlier, this is not the same as the uncertainty in the DAS used in the collection of the field observations. The uncertainty due to the field DAS is discussed in the algorithm theoretical basis document (ATBD) associated with the measurement.

3.2.6 Sensor Drift

Due to the initial calibration coefficients for sensors and initial uncertainty estimations still being assessed, drift will not be a part of this year's assessment of calibrations and sensors.

3.2.7 Traceability Documentation

The uncertainty assessment will denote and verify that the appropriate documentation is in CVAL's possession to show traceability.

3.3 Calibration Uncertainty

Calibration combined uncertainty includes calibration repeatability, calibration reproducibility, truth and lab data acquisition system. All these terms are added in quadrature to represent the calibration uncertainty. Expanded uncertainty is found by multiplying the calibration combined uncertainty by the coverage factor as described in Equation 7 to provide a 95% confidence level. For level zero data, sensor repeatability is included in the combined uncertainty. This combined uncertainty, however, does not represent the calibration uncertainty. For a general overview on how these uncertainty terms are applied to NEON data products, see NEON.DOC.000785.

3.4 Uncertainty Nomenclature

The uncertainty terms described in Section 3.2 are added in quadrature to provide the combined uncertainty. The uncertainty terms are passed to CI in the calibration file corresponding to the relevant sensor. The nomenclature is consistent with the ICD between CVAL and CI and agreed upon with Science needs. Because Science has different application interests, multiple combinations of uncertainty terms are passed. Calibration uncertainties and sensor repeatability are combined to provide an uncertainty term for Level 0 Prime data products. Only the calibration combined uncertainty is used for Level 1 data products. Because Level 1 data products are an average of field observations, sensor repeatability is better estimated with the field observations and the mean product. The sensor repeatability term is passed through as an independent uncertainty term as a comparison value to the sensor repeatability in the field to ensure performance. The following will be associated with each calibration file for sensors:

Sensor Uncertainty:

U_CVALA1: Calibration Combined Uncertainty + U_CVALA2
U_CVALA2: Sensor Repeatability
U_CVALA3: Calibration Combined Uncertainty
U_CVALD1: Degrees of Freedom for U_CVALA1
U_CVALD2: Degrees of Freedom for U_CVALA2
U_CVALD3: Degrees of Freedom for U_CVALA3

GRAPE Uncertainty for Resistance:

U_CVALR1: Calibration Combined Uncertainty + U_CVALA2

U_CVALR2: Sensor Repeatability
U_CVALR3: Calibration Combined Uncertainty
U_CVALR4: Offset
U_CVALF1: Degrees of Freedom for U_CVALR1
U_CVALF2: Degrees of Freedom for U_CVALR2
U_CVALF3: Degrees of Freedom for U_CVALR3

GRAPE Uncertainty for Voltage:

U_CVALV1: Calibration Combined Uncertainty + U_CVALA2

U_CVALV2: Sensor Repeatability
U_CVALV3: Calibration Combined Uncertainty
U_CVALV4: Offset
U_CVALG1: Degrees of Freedom for U_CVALV1
U_CVALG2: Degrees of Freedom for U_CVALV2
U_CVALG3: Degrees of Freedom for U_CVALV3

The values will be maintained in a database drawn on by CVAL automated calibration XML generation. Uncertainties will be reported with two digits of significance for measurand units and three significant figures for relative uncertainties. All uncertainties in relative terms will NOT be reported as a percentage in the XML files for CI computation. For information about how these are applied to the individual data products, a general over view is given in NEON.DOC.000785 and the data product ATBDs provide specific calculations used to determine the reported measurement uncertainty.

4 OUTSIDE FACILITY CALIBRATIONS

Due to CVAL's limitations such as not being able to support a wind tunnel for wind anemometer calibrations, some calibrations rely on the manufacturer or outsourced laboratory to perform the annual calibration. In this event, the quality metrics from this facility will be used and the uncertainty will propagate to the data portal through instruction in the data product's ATBD. In the case of this outside facility calibration, CVAL will validate at limited conditions that the sensors are maintaining consistency in calibration. The below are the calendar YR 2014 outsourced calibrations and a brief description of the validation. Specific methods and metrics that validations are checked against are outlined in the CVAL QA/QC Manual.

4.1 Sunphotometer (CE318; Cimel; Paris, France)

FIXTURE #: L1R300 and L2R300

NEON PART #: CD03060510

The sunphotometers (or CIMELs) for their initial deployment are calibrated and maintained by Aerosol Robotic Network (AERONET) located at NASA's Goddard Space Flight Center in Greenbelt, MD. NASA quotes their uncertainty for the calibration is 5%. Below is a personal communication with Jon Rodriguez of Aeronet for description of the uncertainty estimation:

It's 5.0%. It's kind of a catch-all for the following:
• Uncertainty in the sphere characterization
• Small un-repeatability in the calibrations, due to:
  - *Small drift in the sphere lamps between re-characterizations*
  - *Small differences in temperature or humidity at the time of calibration*

• Setup error

It would likely be possible perform tests to increase the precision and accuracy of the uncertainty. We haven't bothered with this for two reasons. First, because some of our European collaborators do not have the means to characterize their sphere to the level of accuracy that we are able to, so in the interest of standardization we leave it at 5.0%. Second, because it typically takes differences of 10% or more in the sky calibration to have any noticeable impact on the sky measurements (retrievals). Remember that a 5% (or any amount of) uncertainty in the Cimel sky calibration does not translate to a 5% uncertainty in the retrieval products.

Jon Rodriguez, Aeronet NASA (10/27/2014)

Presently, all CIMELs are calibrated by AERONET, but in future, NEON will take over calibrations after all CIMELs are deployed to the network. Presently, in CVAL, the CIMELs are characterized by a labsphere that mimics the set up at AERONET. This characterization occurs under 4 lamp settings (4, 3, 2, and 1 lamp on) in a labsphere. The CIMELs are also characterized outdoors at CVALLA where CVAL owned standards are co-located. These standards are kept in an annual calibration through AERONET. For more information on the validation, see documents NEON.DOC.000745 and NEON.DOC.000801 for indoor and outdoor set-ups, respectively.

The sensors will go through a calibration annually, and upon return, CVAL will calibrate these units. However, that will not happen in this calendar year nor does CVAL have the ability to do this as AERONET needs to first provide a transfer of standard for the labsphere. After this happens, uncertainty of the calibration procedure will be estimated. Further, major maintenance on the CIMEL such as filter swapping or collimator repair will only occur at AERONET for the near future at which point a recalibration of this unit at NASA will occur and characterization at NEON will follow. Calibrations at NASA will take precedence over in-house calibrations.

4.2 2-D Wind Anemometer (WOII; Gill; Lymington, Hampshire, UK)

FIXTURE #: L2B100

NEON PART #: CD00310000 (heated) and CD00310010 (unheated)

The 2-D wind anemometers by Gill are calibrated at their facility with both zero wind and wind tunnel tests. The quoted accuracy for the instrument is +/- 2% at 12 m/s. However, personal communications with NEON scientists has provided them a metric that is outlined in the ATBD how to propagate uncertainty for the calibration and sensor. The anemometers are then validated at CVALLA where they are mounted on an A-frame structure and co-located with CSAT 3-D anemometer CVAL standards. These standards are calibrated annually at Campbell Scientific in Logan, UT (See section 4.3). For more information on the validation, see NEON.DOC.000902. The sensors are validated annually, and if the results do not meet NEON requirements, the sensors are sent back to Gill for maintenance and/or calibration.

4.3 3-D Wind Anemometer (CSAT; Campbell Scientific; Logan, UT)

FIXTURE #: L2B200

NEON PART #: 0300010000

The 3-D wind anemometers (CSATs) by Campbell Scientific are calibrated at their facility with both transducer geometry and zero-wind temperature chamber tests. The uncertainty for the calibration of the Ux and Uy offset is ± 2 cm/s and ± 1 cm/s for the Uz offset . Similar to 2-D anemometers, the CSATs are validated at CVALLA on an A-frame structure with co-located CSAT standards. For more information on the validation, see NEON.DOC.002475. The sensors are validated annually, and if the results do not meet NEON requirements, the sensors are sent back to Gill for maintenance and/or calibration.

4.4 Soil Moisture (TriSCAN; Sentek; Stepney, SA, AUS)

FIXTURE #: L1W300

NEON PART #: CF00850000

In the case of the soil moisture sensor, the sensor is only normalized at NEON for high and low frequencies in both dry air and deionized water for moisture and ion content readings. For more information on the normalization, see NEON.DOC.001084. The calibration coefficients are associated with the site specific soils. This calibration is what impacts the uncertainty of the sensor output and will be quantified by testing at the facility in cooperation with NEON scientists. The ATBD outlines how this will be accomplished. The sensor will be characterized for the high low frequencies on an annual basis and be programed with the site-specific coefficients in-house.

4.5 Nutrient Analyzer (SUNA V2; Satlantic; Halifax, Canada)

FIXTURE #: L1A200

NEON PART #: 0329950000

The SUNA will be maintained and calibrated annually by Satlantic. Because of the length of the lamp life (~900 hours), the lamp on the sensor is replaced annually at which point a recalibration takes place. CVAL will perform a 2-point validation at zero and 100 mg/L of nitrogen-nitrate standard solution. These solutions will be NIST traceable since Satlantic calibration solutions are not traceable. For more information on the validation, see NEON.DOC.001216. The sensors will be validated annually and if a discrepancy is found between the solutions and sensor, the sensor will be returned to the Satlantic for maintenance and/or recalibration.

4.6 Particulate Analyzer (DustTrak DRX 8533EP; TSI; Shoreview, MN)

FIXTURE #: L1J100

NEON PART #: 0330570000

TSI will calibrate NEON DustTrak sensors on an annual basis. Their calibration includes aerosol concentration, flow and pressure verification tests. Tolerances for these are 10%, 5%, and 5%, respectively. Presently, CVAL does not have the ability to validate aerosol concentrations. Therefore, only a functionality test is performed on the sensor. For more information on the functionality test, see NEON.DOC.002429.

5 PLATINUM RESISTANCE THERMOMETER (THERMOMETRICS CORP; NORTHRIDGE, CA)

FIXTURE #: L1T200

NEON PART #: AB03950006 (submersible) and CA00110002 (aspirated)

CALIBRATION DESCRIPTION: The calibration utilizes a Standard Platinum Resistance Thermometer (SPRT) 5626 by Fluke (American Fork, UT) to calibrate up to 15 PRTs which are considered the UUT in this case. The SPRTs are calibrated in-house with 3 fixed point cells for MPGa, TPW, TPHg (5943, 5901, 5900, Fluke, American Fork, UT), respectively. The PRT calibration is performed in 3 baths; 1 contains DI water and is used for the 50°C set point and 2 contain 95% ethanol with 5% DI water that are run at 0 and -30°C. These points were selected to yield the most accurate calibrations. For more information on the calibration, see NEON.DOC.000723. The uncertainty evaluation resulted in Y = y ± 0.011°C with 95% level of confidence. Values can be seen in Table 1 with details of the evaluation are below.

Table 1: PRT Calibration Uncertainty Estimation 2014.

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	SPRT Calibration	B	100	1.2E-04
Repeatability	Calibration Repeatability	A	60	9.0E-04
DAS	(2x) CVAL NI DMM ED4305 PXI-4071	B	100	1.4E-05
Mux Box	(2x) Testing with 115 ohm resistor	A	32.8	9.1E-05
Reproducibilty	Calibration Roproducibility	A	8	4.8E-03
Repeatability	Sensor Repeatability	A	20	2.6E-03
Combined	Calibration Combined Uncertainty	eff	8	0.005
Expanded	Calibration Expanded Uncertainty	k	2.36	0.011

TRUTH: The SPRT Calibration is performed in house and follows the NIST Special Publication by Strouse (2008). In this document, the uncertainties are detailed as related with the calibration with the fixed point cells. Because the calibration performed by CVAL emulates these procedures, Type B evaluation was used from this published knowledge. However, in future, a Type A evaluation may be justified.

CALIBRATION REPEATABILITY: Calibration data from 210 UUTs was used for this analysis. The 20 data points of the 3 temperatures (50, 0, and -30 °C) used for fitting the curve were used to calculate the difference between the standard and the UUT.

DAS: Uncertainty values from the following document was used National Instruments_PXI-4071_Serial Number EFEBC2.pdf as a Type B evaluation from a calibration certificate. The PXI-4071 used in the PRT calibration goes through the same calibration as the one detailed in this document, so the uncertainties were considered the same. The associated resistance calibration point was the 1k Ohm for 4 wire resistance which is consistent with the fixture wiring set-up. The calibration coefficients for 31 sensors and the resistance range of 120 through 88 ohms which corresponds to 50 through -30°C were used to transform the uncertainty into °C using the partial derivative of the second order polynomial. Therefore the uncertainty follows Equation 12:

$$u(y\,°C) = [2 * C \qquad 2 * (K) + C \qquad 1] * u(D \quad ohm\ ) \tag{12}$$

where R is the resistance taken through 120 through 88, CVALA2 and CVALA1 are calibration coefficients for a given sensor and u(DAS ohms) is from the calibration certificate noted above. Because the SPRT and PRT are taken through the same DAS, the contributing uncertainty is multiplied by two when adding in quadrature.

MUX BOX: The calibration of PRTs is taken through a mux box; therefore the uncertainty associated with switching through the 16 ports was determined using a 115 precision ohm resistor by Vishay (115R4920-5102K). 20 readings were taken on each port to determine the repeatability per port and reproducibility across the 16 ports. Finally, the reading of the precision resistor was taken without the mux box in place (i.e. directly into the DMM) and this reading was considered the truth for the " calibration repeatability" calculation. These uncertainties were added in quadrature, and the effective degrees of freedom was used from these experiments. Because the SPRT and PRT are taken through the same DAS, the contributing uncertainty is multiplied by two when adding in quadrature.

CALIBRATION REPRODUCIBILITY: Eight operators with 8 different SPRTs calibrated by CVAL were used to assess the variation of standards and multiple operators. The resistance range of 120 to 88 ohms was used to evaluate the 15 PRTs resulting calibration coefficients. The standard deviation of the predicted temperatures for the 8 calibrations was used for this term.

SENSOR REPEATABILITY: The calibration uses 20 readings at each set point to determine the calibration fit, therefore, 20 readings were used for the repeatability testing. The same calibration data from the 210 UUTs utilized in the calibration repeatability assessment was used.

TRACEABILITY: All documents as they apply to operating YR2014 were located for the calibrations of SPRTs and PRTs and can be found in Table 2. Table 3 provides an outline of the relevant requirements as they apply to the calibration. The PRT calibration is in compliance with the requirements.

Table 2: Document Traceability for the SPRT and PRT Calibrations.

Traceability of the PRT Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5901D Triple Point of Water	Fluke Corporation_5901D-Q The Triple Point of Water Cell_Serial Number D-Q1114.pdf	Triple Point of Water
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5901D Triple Point of Water	Fluke Corporation_5901D-Q The Triple Point of Water Cell_Serial Number D-Q1069.pdf	Triple Point of Water
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury	Fluke Corporation_5900E Triple Point of Mercury Cell_Serial Number Hg-00028.pdf	Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury	Fluke Corporation_5900E Triple Point of Mercury Cell_Serial Number Hg-00036.pdf	Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury		Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5943 Melting Point of Gallium	Fluke Corporation_5943 Melting Point of Gallium Cell_Serial Number Ga-43149.pdf	Melting Point of Gallium
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5943 Melting Point of Gallium	Fluke Corporation_5943 Melting Point of Gallium Cell_Serial Number Ga-43114.pdf	Melting Point of Gallium
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\9230 Calibration Furnace	Fluke Corporation_9230_Calibration Furnace_Serial Number B38119.pdf	Gallium Maintenance Cell
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\9230 Calibration Furnace	Fluke Corporation_9230 Gallium Cell Maintenance Apparatus_Serial Number B08088.pdf	Gallium Maintenance Cell
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	National Instruments_PXI-4071_Serial Number ED4305_2013.pdf	National Instrument 7Â½ DMM and 1000 V Digitizer
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001183_WO1001_17048.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001182_WO1000_17046.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000051571_WO1002_17044.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050167_WO196_17042.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050166_WO195_17047.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050165_WO194_17043.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001184_WO955_17045.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050156_WO193_17049.xml	SPRT Calibration Files
N:\DEPT\CVL\QAQC\PRT	SPRT_Summary_2014.xlsx	SPRT Calibration History File

Table 3: Requirements for the SPRT and PRT Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by
	providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of
	the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible,
	standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital
	multimeters, millivolt sources, and counters
NEON.CVAL.3.1010	Triple point cells (Gallium (26.77165 °C) and Mercury (-38.83444 °C)) and an ice-water bath (0 °C) shall be used as a reference for calibration of all in
	situ (air, soil, and water) temperature sensors (e.g. platinum resistance thermometers) prior to deployment and at a minimum annually. NEON.CV.3.007
NEON.CVAL.3.1011	Air temperature sensors shall be calibrated to achieve a 0.1 °C accuracy.
NEON.CVAL.3.1012	Soil and water temperature sensors shall be calibrated to achieve a 0.15 °C accuracy
NEON.TIS.4.1132	All temperature measurements in the air and soil environments shall have an accuracy of < ±0.1 °C, and precision to < ±0.05 °C.

6 BIOLOGICAL TEMPERATURE (SI-111; APOGEE; LOGAN, UT)

FIXTURE #: L1R600

NEON PART #: CA02460000 (tower) and CF03210000 (soil)

CALIBRATION DESCRIPTION: The calibration utilizes a Fluke Precision Infrared Calibrator (4180, American Fork, UT) to calibrate one sensor. The sensor's body temperature is controlled to designated set points using a solid state cold plate (AHP-301 CPHC, ThermoElectric Cooling Americ Corp, Chicago, IL). The calibration with the blackbody calibrator entails a set of five black body temperatures at a given controlled body temperature which are fit to a linear function of a modified version of the Stefan-Boltzmann Law where emitted energy is proportional to the temperature to the fourth power. Body temperatures range from -5°C to 45°C in 10°C increments. The calibration set points utilize temperatures of the black body versus the temperature of the sensor body such that the difference is +20, +10, 0, -10, and -20°C where possible. The black body temperature minimum is -15°C due to environmental and operating constraints of the calibrator. For more information on the calibration, see NEON.DOC.000744. The uncertainty evaluation resulted in Y = y ± 0.60°C with 95% level of confidence. Values can be seen in Table 4 with details of the evaluation are below.

Table 4: Bio Temp Calibration Uncertainty Estimation 2014.

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Fluke Calibrator	B	100	1.3E-01
Repeatability	Calibration Repeatability	A	300	2.7E-01
DAS	CVAL NI DMM ED4305 PXI-4071 (voltage)	B	100	2.0E-02
DAS	CVAL NI DMM ED4305 PXI-4071 (resistance)	B	100	1.9E-04
Reproducibilty	Calibration Reproducibility	A	12	5.7E-02
Repeatability	Sensor Repeatability (voltage)	A	10	1.1E-01
Repeatability	Sensor Repeatability (reistance)	A	10	2.6E-02
Combined	Calibration Combined Uncertainty	eff	401	0.31
Expanded	Calibration Expanded Uncertainty	k	1.97	0.60

CAVEAT: This estimation is only for the temperature range of -15°C to 65°C and a difference between sensor body temperature and target temperature up to 20°C. Estimations for <-15°C are not possible due to the condensation risk on the black body.

TRUTH: The IR Blackbody calibrator is calibrated annually by Fluke and provides an expanded uncertainty for the calibration of ±0.2°C with coverage factor of 2 (k=2) for the temperature range of use. The emissivity setting for this Fluke calibration is 0.95, but the calibration for the IR sensor, the emissivity is set to 1.00. However, stability, uniformity, and resolution are also taken into consideration as described by Fluke (2007b) section 6.9 which should cover the range of emissivity from 0.9 to 1.00.

CALIBRATION REPEATABILITY: Calibration data from 3 sensors were used in the calibration repeatability determination. The difference between the sensor's predicted versus the IR calibrator target temperature was used to calculate this uncertainty.

DAS: Target Voltage: Taking the derivative of Equation 13 with respect to the target mV results in Equation 14 which is then multiplied by the DMM uncertainty according to the most recent calibration certificate. T_T is target temperature, T_B is body temperature, and m_{cx} and b_{cx} are coefficients generated by the calibration.

$$T_T^4 - T_B^4 = m \cdot (m\quad) + b \tag{13}$$

where:

$$m = m_{c2} \cdot T_B^2 + m_{c1} \cdot T_B + m_{c0}$$

$$b = b_{c2} \cdot T_B^2 + b_{c1} \cdot T_B + b_{c0}$$

$$\frac{d\ _T}{d(m\ )} = \frac{1}{4}(m \cdot (m\quad) + b + T_B^4)^{-3/4} \cdot m \tag{14}$$

Body Resistance: Taking the derivative of Equation 13 with Equation 15 inserted into the T_B term, the derivative of the target temperature with respect to the body resistance (R_B) results in Equation 16 which is then multiplied by the DMM uncertainty according to the most recent calibration certificate. The shunt resistor added to the thermistor to accommodate the GRAPE is a 604 Ω resistor. By using the following relationship: $R_B = R_T \cdot 604/(R_T+604)$, the thermistor resistance (R_T) can be calculated. Coefficients A, B, and C were acquired from the thermistor manufacturer and are consistent for all IR sensors.

$$T_B = \frac{1}{A + B \cdot l\ \left(\frac{-604 \cdot R_B}{R_B - 604}\right) + C\left(l\ \left(\frac{-604 \cdot R_B}{R_B - 604}\right)\right)^3} \tag{15}$$

where:

$$A = 1.129241 \cdot 10^{-3}$$
$$B = 2.341077 \cdot 10^{-4}$$
$$C = 8.775468 \cdot 10^{-8}$$

$$\frac{d\ _T}{dR_B} = \frac{1}{4}(m_{c2} \cdot T_B^2 \cdot m\quad + m_{c1} \cdot T_B \cdot m\quad + m_{c0} \cdot m\quad + b_{c2} \cdot T_B^2 + b_{c1} \cdot T_B + b_{c0} + T_B^4)^{-3/4} \cdot (2m_{c2} \cdot T_B \cdot m\quad + m_{c1} \cdot m\quad + 2b_{c2} \cdot T_B + b_{c1} + 4T_B^3) \cdot \tag{16}$$

$$\left[-\left(A+B\cdot ln\left(\frac{-604\cdot R_B}{R_B-604}\right)+C\left(ln\left(\frac{-604\cdot R_B}{R_B-604}\right)\right)^3\right)^{-2}\right]\cdot\left[B+3\cdot C\left(ln\left(\frac{-604\cdot R_B}{R_B-604}\right)\right)^2\right]$$
$$\cdot\left[\frac{-604}{R_B\cdot(R_B-604)}\right]$$

CALIBRATION REPRODUCIBILITY: Eight operators with three different sensors were used to assess the reproducibility of the calibration. The standard deviation of the predicted temperatures for twelve calibrations of one sensor was used for this term.

SENSOR REPEATABILITY: The calibration uses 10 readings at each set point to determine the calibration fit, and therefore, 10 readings were used for the repeatability testing. Standard deviation was taken from the 30 calibrations' voltage and resistance data at each set point, and equations 14 and 16 were used to translate the deviations to uncertainties in °C.

TRACEABILITY: Two documents are missing for the operating YR2014 and two were located with details in Table 5. The two missing documents have been requested and the DMM has been confirmed to be in calibration. Table 6 provides an outline of the relevant requirements as they apply to the calibration. The requirement NEON.CVAL.4.1002 depending on the interpretation of accuracy seems to be unattainable given the limitations of the calibration. The calibration has been significantly tested and the higher uncertainty seems to be due to limitations of the technology. The requirements were written in accordance with the manufacturer's specifications. However, NEON made a modification to the sensor's output by adding a shunt resistor to step down the reading for tolerance with the field data acquisition system's range. Therefore, this will add to the overall uncertainty and thus a slightly higher uncertainty should be expected.

Table 5: Document Traceability for the Biological Temperature Sensor Calibrations.

Traceability of the IR Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\4180 IR Calibrator	Fluke Corporation_4180_IR Calibrator SN B1A370_2013.pdf	Blackbody Standard Cal Cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\4180 IR Calibrator	Fluke Corporation_4180_IR Calibrator SN B36546.pdf	Blackbody Standard Cal Cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071		Resistance National Instruments PXI-4071 DMM
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071		Voltage National Instruments PXI-4071 DMM

Table 6: Requirements for the Biological Temperature Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by
	providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of
	the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible,
	standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital
	multimeters, millivolt sources, and counters
NEON.CVAL.3.1016	A minimum of 5 black- body temperatures selected to span the range of expected temperatures at the relevant deployment site shall be used to
	calibrate the standard.
NEON.CVAL.3.1015	Infra-red temperature measurements shall be calibrated prior to deployment and at least annually using transfer standards traceable to a blackbody
	cavity (e » 0.999) that is stable, ±2 W or better (i.e., emissivity temperatures to ±0.1 °C) for a minimum of 1 day.
NEON.CVAL.4.1002	Infra-red temperature measurements shall be calibrated to ±0.5 °C.

7 BAROMETRIC PRESSURE (PTB330; VAISALA; LOUISVILLE, CO)

FIXTURE #: L1E100

NEON PART #: CA01680000

CALIBRATION DESCRIPTION: Up to five sensors are calibrated with a Fluke Pressure Controller/Calibrator (PPC4, Phoenix, AZ). The controller ranges the pressure from 500 to 1100 hPa through nine set points. Because an internal correction is made for temperature, uncertainty over the range of operating conditions is to be included in the uncertainty assessment. For more information on the calibration, see NEON.DOC.000735. The uncertainty evaluation resulted in Y = y ± 0.18 hPa with 95% level of confidence. Values can be seen in Table 7 with details of the evaluation are below.

Table 7: Barometric Pressure Calibration Uncertainty Estimation 2014.

All Uncertainties given in hPa		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	PPC4	B	100	4.4E-02
Repeatability	Calibration Repeatability	A	207	9.8E-03
Temperature	Temperature	A	5	1.6E-02
Reproducibilty	Calibration Reproducibility	A	14	7.1E-02
Repeatability	Sensor Repeatability	A	23	8.9E-03
Combined	Calibration Combined Uncertainty	eff	27	0.086
Expanded	Calibration Expanded Uncertainty	k	2.06	0.18

TRUTH: The PPC 4 technical note 8050TN11 (Bair, 2009) provides calculations for uncertainty. This uncertainty calculation considers operation mode, fluid media, environment, orientation, reference uncertainty, calibration frequency, auto-zero frequency, control precision, and dwell (short term stability) as sources. These uncertainties are calculated in real-time with the calibration and are described by Fluke as the "delivered" uncertainty.

CALIBRATION REPEATABILITY: Calibration data from 3 sensors were used in the calibration repeatability determination. The difference between the sensor's predicted versus the IR calibrator target temperature was used to calculate this uncertainty.

DAS: Because the signal from the sensor is digital, no uncertainty added for data acquisition.

TEMPERATURE: Temperature variation was evaluated at five different temperatures (-29, -10, 10, 30, and 50 °C) with the same sensor. Maximum difference of the five temperatures over the pressure ranges of the calibration (500-1100 hPa) was used to calculate uncertainty.

CALIBRATION REPRODUCIBILITY: Eight operators with five different sensors were used to assess the reproducibility of the calibration. The standard deviation of the predicted pressures for fourteen calibrations of one sensor was used for this term.

SENSOR REPEATABILITY: The calibration uses 23 readings at each set point to determine the calibration fit, and therefore, 23 readings were used for the repeatability testing. Standard deviation was taken from the five calibrations' pressure data at each set point with the maximum taken.

TRACEABILITY: All documents for the two standards were located with details in Table 8. Table 9 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 8: Document Traceability for the Barometric Pressure Sensor Calibrations.

Traceability of the PRT Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\PPC4 Pressure Calibrator	Fluke, PPC4, Pressure Calibrator SN1063.pdf	PPC4 calibration cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\PPC4 Pressure Calibrator	Fluke, PPC4, Pressure Calibrator SN758_Oct2013.pdf	PPC4 calibration cert

Table 9: Requirements for the Barometric Pressure Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by
	providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of
	the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible,
	standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital
	multimeters, millivolt sources, and counters
NEON.CVAL.4.1041	The accuracy of static atmospheric pressure sensors shall be calibrated to ±0.1 kPa.

8 NET RADIOMETER: PYRGEOMETER (NR01; HUKSEFLUX; DELFT, NETHERLANDS)

FIXTURE #: L2R200

NEON PART #: CF03220000 (soil) and CA02770000 (tower)

CALIBRATION DESCRIPTION: Up to ten sensors are calibrated outdoors at CVALLA during clear sky night conditions against the reference pyrgeometer (CGR4; Kipp & Zonen; Delft, Netherlands). Because a single sensor has both an upward and downward facing pyrgeometer, the full calibration cycle for one sensor requires two calibration periods in which the sensor is flipped during one period (the calibration occurs for a given pyrgeometer when facing the night sky. Data is parsed clear sky conditions and cleaned for a net exchange on the reference of less than -70 W/m^2; this provides for quality calibration data. For more information on the calibration, see NEON.DOC.000802. The uncertainty evaluation resulted in Y = y ± 5.8 W/m^2 with 95% level of confidence. Values can be seen in Table 10 with details of the evaluation are below.

Table 10: Net Radiometer Pyrgeometer Calibration Uncertainty Estimation 2014.

All Uncertainties given in W/m^2		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	CGR4	B	100	1.40
Repeatability	Calibration Repeatability	A	2853	1.61
DAS	Mux Box (UUT)	A	55	0.46
DAS	Mux Box (Ref)	A	55	0.45
DAS	CR3000 (UUT)	B	100	0.20
DAS	CR3000 (Ref)	B	100	0.21
Reproducibilty	Calibration Reproducibility	A	8	1.80
Repeatability	Sensor Repeatability	A	305	0.82
Combined	Calibration Combined Uncertainty	eff	44	2.9
Expanded	Calibration Expanded Uncertainty	k	2.02	5.8

CAVEAT: Reproducibility and repeatability calibrations used for this analysis had a few issues. The signal on the PRTs were inversed at one point, the program has gone through several revisions through learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The CGR4 by Kipp and Zonen is calibrated at NREL annually against their standard which is traceable to the World Infrared Standard Group (WISG). The calibration occurs outdoors under variable sky conditions. The expanded uncertainty from NREL is 2.8 W/m^2 with a coverage factor of 2.

CALIBRATION REPEATABILITY: Calibration data from 29 calibrations were used in the calibration repeatability determination. The difference between the CGR4 and the NR01's calculated long wave radiation was used to calculate this uncertainty.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for both the UUT and reference. Resistance was tested with a precision resistor at 115 Ω resulting in an uncertainty of 1.8 mΩ, and voltage was tested with a fluke precision voltage source at 20 mV resulting in an uncertainty of 4.5 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming a normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. Again, both the UUT and reference are accounted for since data is logged for both sensors on the same DAS.

CALIBRATION REPRODUCIBILITY: A single sensor was evaluated for reproducibility over eight different calibration periods. While these span a half year, the seasonal component was not fully captured. The calibrations occurred in October and April. The standard deviation of the predicted long wave radiation of one sensor was used for this term.

SENSOR REPEATABILITY: Repeatability was tested indoors with an IR calibrator and body temperature was controlled at a constant temperature for resistance repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 11. Table 12 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 11: Document Traceability for the Net Radiometer Pyrgeometer Sensor Calibrations.

Traceability of the NR01 Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6041.pdf	CR3000
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CGR4 serial number 130572.pdf	CGR4 NREL Certificate

Table 12: Requirements for the Net Radiometer Pyrgeometer Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques.
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1021	Longwave working standard sensors shall be calibrated against a traceable black-body radiation source for three different temperatures spanning the range of the annual mean temperature at the relevant field site.
NEON.CVAL.3.1022	Longwave field sensors shall be calibrated against working standard field pyrgeometers prior to deployment and at least annually
NEON.CVAL.4.1007	Longwave sensor calibrations shall be traceable to Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (WRC) protocols.
NEON.CVAL.4.1008	Longwave sensors shall achieve an accuracy of ± 6 W/meter^2.
NEON.CVAL.4.1014	Net radiation sensors shall be calibrated to within ±10% of daily totals.
NEON.CVAL.3.1028	Net radiation sensors shall be calibrated prior to deployment and at a minimum annually against working standard radiation sensors.

9 NET RADIOMETER: PYRANOMETER (NR01; HUKSEFLUX; DELFT, NETHERLANDS)

FIXTURE #: L2R700

NEON PART #: CA02770000

CALIBRATION DESCRIPTION: Up to ten sensors are calibrated outdoors at CVALLA during clear day-time sky conditions. The calibration has two options for references: Option A is the reference pyranometer (CMP22; Kipp & Zonen; Delft, Netherlands) and Option B utilizes two references: a pyroheliometer (CHP1; Kipp & Zonen) and shaded pyranometer (CMP22; Kipp & Zonen) located on a sun tracker (SOLYS2; Kipp & Zonen), which are used to calculate the global shortwave radiation (the output of the NR01). Because a single sensor has both an upward and downward facing pyranometer, the full calibration cycle for one sensor requires two calibration periods in which the sensor is flipped during one period (the calibration occurs for a given pyranometer when facing the day sky). Data is parsed for clear sky conditions and cleaned for outliers, which provides for quality calibration data. For more information on the calibration, see NEON.DOC.002213. The uncertainty evaluation resulted in Y = y ± 2.21% and ± 1.91% with 95% level of confidence for the reference Option A and Option B, respectively. Values can be seen in Tables 13 and 14 for the respective calibrations with details of the evaluation are below.

Table 13: Net Radiometer Pyranometer Calibration with Reference Pyranometer (Option A) Uncertainty Estimation 2014.

All Uncertainties given in %		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	CMP22 (Global)	B	319749	0.65%
Repeatability	Calibration Repeatability	A	1576	0.66%
DAS	Mux Box	A	56	0.041%
DAS	Mux Box (ref)	A	56	0.048%
DAS	Campbell Sci CR3000 (UUT)	B	100	0.033%
DAS	Campbell Sci CR3000 (ref)	B	100	0.035%
Reproducibilty	Calibration Reproducibilty	A	11	0.613%
Repeatability	Sensor Repeatability	A	106	0.00867%
Combined	Calibration Combined Uncertainty	eff	109	1.12%
Expanded	Calibration Expanded Uncertainty	k	1.98	2.21%

Table 14: Net Radiometer Pyranometer Calibration with Reference Pyrheliometer with Shaded Pyranometer (Option B) Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Pyroheliometer & CMP(Diffuse)	B	42022	0.29%
Repeatability	Calibration Repeatability	A	1576	0.66%
DAS	Mux Box	A	56	0.041%
DAS	Mux Box (ref)	A	56	0.075%
DAS	Campbell Sci CR3000 (UUT)	B	100	0.033%
DAS	Campbell Sci CR3000 (ref)	B	100	0.037%
Reproducibilty	Calibration Reproducibilty	A	11	0.613%
Repeatability	Sensor Repeatability	A	106	0.00867%
Combined	Calibration Combined Uncertainty	eff	58	0.955%
Expanded	Calibration Expanded Uncertainty	k	2.00	1.91%

CAVEAT: Reproducibility and repeatability calibrations used for this analysis had a few issues. The program has gone through several revisions through learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Also, the calibration with references of the pyrheliometer with shaded pyranometer (Option B) has not been utilized for an extended period of time to allow for extensive uncertainty testing. Therefore, only the uncertainty of the truth (NREL calibration uncertainties) and DAS components of uncertainty are fully assessed, while sensor repeatability, calibration repeatability , and reproducibility values are taken from the pyranometer calibration (Option A) assuming that Option B would result in the same or better uncertainties. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The CMP22s and CHP1 by Kipp and Zonen are calibrated at NREL annually against their standards which are traceable to the World Radiometric Reference (WRR) and World Infrared Standard Group (WISG). The calibration occurs outdoors against a pyrheliometer and shading disk for reference diffuse installed on solar trackers. The expanded uncertainty from NREL for the pyranometers using the spline interpolation (which is utilized in CVAL's program) is 1.28% and for the pyrheliometer is 0.66% all with a coverage factor of 1.96. Additionally, the zenith angle is a component of the calculations and CVAL acquires zenith angle data from NREL's solar position algorithm which has an uncertainty of ±0.0003° (Reda and Andreas, 2004).

CALIBRATION REPEATABILITY: Calibration data from 17 calibrations were used in the calibration repeatability determination. The difference between the calculated reference and the NR01's calculated short wave radiation was used to calculate this uncertainty. The calibration repeatability from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for both the UUT and reference. Voltage was tested with a fluke precision voltage source at 20 mV and resulted in an uncertainty of 4.5 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming a normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. Again, both the UUT and reference/s are accounted for since data is logged for all sensors on the same DAS.

CALIBRATION REPRODUCIBILITY: A single sensor was evaluated for reproducibility over eleven different calibration periods. While these span a half year, the seasonal component was not fully captured. The calibrations occurred in March to July. The standard deviation of the predicted short wave radiation of one sensor was used for this term. The reproducibility from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

SENSOR REPEATABILITY: Repeatability was tested indoors with a Labsphere source which provides a stable radiation source for signal repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 15. Table 16 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 15: Document Traceability for the Net Radiometer Pyranometer Sensor Calibrations.

Traceability of the PAR Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6041.pdf	CR3000
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Global
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Diffuse
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CHP1

Table 16: Requirements for the Net Radiometer Pyranometer Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1006	NEON shortwave radiation sensors shall be calibrated to ± 6 W/meter^2 for primary sensors and ± 10 W/meter^2 for secondary sensors.
NEON.CVAL.4.1014	Net radiation sensors shall be calibrated to within ±10% of daily totals.
NEON.CVAL.3.1028	Net radiation sensors shall be calibrated prior to deployment and at a minimum annually against working standard radiation sensors.

10 PRIMARY PYRANOMETER (CMP22; KIPP & ZONEN; DELFT, NETHERLANDS)

FIXTURE #: L2R800

NEON PART #: CA00170000

CALIBRATION DESCRIPTION: Up to eight sensors (with expansion capability for sixteen) are calibrated outdoors at CVALLA during clear day-time sky conditions. The calibration has two options for references: Option A is the reference pyranometer (CMP22; Kipp & Zonen; Delft, Netherlands) and Option B utilizes two references: a pyroheliometer (CHP1; Kipp & Zonen) and shaded pyranometer (CMP22; Kipp & Zonen) located on a sun tracker (SOLYS2; Kipp & Zonen), which are used to calculate the global portion of radiation. Data collected at CVALLA is parsed for clear sky conditions and cleaned for outliers, which provides for quality calibration data. For more information on the calibration, see NEON.DOC.000800. The uncertainty evaluation resulted in Y = y ± 1.64 % and ± 1.18% with 95% level of confidence for the reference Option A and Option B, respectively. Values can be seen in Tables 17 and 18 for the respective calibrations with details of the evaluation below.

Table 17: Primary Pyranometer Calibration with Reference Pyranometer (Option A) Uncertainty Estimation 2014.

All Uncertainties given in %		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	CMP22 (Global)	B	319749	0.65%
Repeatability	Calibration Repeatability	A	1289	0.47%
DAS	Mux Box (UUT)	A	56	0.051%
DAS	Mux Box (ref)	A	56	0.048%
DAS	Campbell Sci CR3000 (UUT)	B	100	0.036%
DAS	Campbell Sci CR3000 (ref)	B	100	0.035%
Reproducibilty	Calibration Reproducibilty	A	12	0.214%
Repeatability	Sensor Repeatability	A	114	0.0319%
Combined	Calibration Combined Uncertainty	eff	2109	0.834%
Expanded	Calibration Expanded Uncertainty	k	1.96	1.64%

Table 18: Primary Pyranometer Calibration with Reference Pyrheliometer with Shaded Pyranometer (Option B) Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Pyroheliometer & CMP(Diffuse)	B	42022	0.29%
Repeatability	Calibration Repeatability	A	1289	0.47%
DAS	Mux Box (UUT)	A	56	0.051%
DAS	Mux Box (ref)	A	56	0.075%
DAS	Campbell Sci CR3000 (UUT)	B	100	0.036%
DAS	Campbell Sci CR3000 (ref)	B	100	0.037%
Reproducibilty	Calibration Reproducibilty	A	12	0.214%
Repeatability	Sensor Repeatability	A	114	0.0319%
Combined	Calibration Combined Uncertainty	eff	575	0.60%
Expanded	Calibration Expanded Uncertainty	k	1.96	1.18%

CAVEAT: Reproducibility and calibration repeatability calibrations used for this analysis had a few issues. The program has gone through several revisions with learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Also, the calibration with references of the pyrheliometer with shaded pyranometer (Option B) has not been utilized for an extended period of time to allow for extensive uncertainty testing. Therefore, only the uncertainty of the truth (NREL calibration uncertainties) and DAS components of uncertainty are fully assessed, while sensor repeatability, calibration repeatability and reproducibility values are taken from the pyranometer calibration (Option A) assuming the Option B would result in the same or better uncertainties. Additionally, a limited number of CMP22 sensors have been available for testing, so calibration repeatability is based on 3 sensors and multiple calibration periods used for reproducibility testing. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The CMP22s and CHP1 by Kipp and Zonen are calibrated at NREL annually against their standards which are traceable to the World Radiometric Reference (WRR) and World Infrared Standard Group (WISG). The calibration occurs outdoors against a pyrheliometer and shading disk for reference diffuse installed on solar trackers. The expanded uncertainty from NREL for the pyranometers using the spline interpolation (which is utilized in CVAL's program) is 1.28% and for the pyrheliometer is 0.66% all with a coverage factor of 1.96. Additionally, the zenith angle is a component of the calculations and CVAL acquires zenith angle data from NREL's solar position algorithm which has an uncertainty of ±0.0003° (Reda and Andreas, 2004).

CALIBRATION REPEATABILITY: Calibration data from 17 calibrations were used in the calibration repeatability determination. The difference between the calculated reference and the CMP22's calculated short wave radiation was used to calculate this uncertainty. The calibration repeatability from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for both the UUT and reference. Voltage was tested with a fluke precision voltage source at 20 mV and resulted in an uncertainty of 4.5 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. Again, both the UUT and reference/s are accounted for since data is logged for all sensors on the same DAS.

CALIBRATION REPRODUCIBILITY: A single sensor was evaluated for reproducibility over twelve different calibration periods. These cover two months (June and July); therefore, the seasonal component was not fully captured. The standard deviation of the predicted short wave radiation of one sensor was used for this term. The reproducibility from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and Option B is a more accurate calibration method.

SENSOR REPEATABILITY: Repeatability was tested indoors an LED source which provides a stable radiation source for signal repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 19. Table 20 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 19: Document Traceability for the Primary Pyranometer Sensor Calibrations.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6041.pdf	CR3000
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Global
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Diffuse
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CHP1

Table 20: Requirements for the Primary Pyranometer Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1006	NEON shortwave radiation sensors shall be calibrated to ± 6 W/meter^2 for primary sensors and ± 10 W/meter^2 for secondary sensors.

11 SUNSHINE PYRANOMETER: GLOBAL (SPN1; DELTA-T; CAMBRIDGE, UK)

FIXTURE #: L2R400

NEON PART #: CA00180000

CALIBRATION DESCRIPTION: Up to eight sensors (with expansion capability for sixteen) are calibrated outdoors at CVALLA during clear day-time sky conditions. The calibration has two options for references: Option A is the reference pyranometer (CMP22; Kipp & Zonen; Delft, Netherlands) and Option B utilizes two references: a pyroheliometer (CHP1; Kipp & Zonen) and shaded pyranometer (CMP22; Kipp & Zonen) located on a sun tracker (SOLYS2; Kipp & Zonen), which are used to calculate the global shortwave radiation. Data is parsed for clear sky conditions and cleaned for outliers, which provides for quality calibration data. For more information on the calibration, see NEON.DOC.000794. The uncertainty evaluation resulted in Y = y ± 3.18% and ± 2.98% with 95% level of confidence for the reference Option A and Option B, respectively. Values can be seen in Tables 21 and 22 for the respective calibrations with details of the evaluation below.

Table 21: Sunshine Pyranometer: Global Calibration with Reference Pyranometer (Option A) Uncertainty Estimation 2014.

All Uncertainties given in %		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	CMP22 (Global)	B	319749	0.650%
Repeatability	Calibration Repeatability	A	3809	1.25%
DAS	Mux Box (ref)	A	56	0.0478%
DAS	Campbell Sci CR3000 (ref)	B	100	0.0348%
Reproducibilty	Calibration Reproducibility	A	9	0.785%
Repeatability	Sensor Repeatability	A	348	0.707%
Combined	Calibration Combined Uncertainty	eff	140	1.61%
Expanded	Calibration Expanded Uncertainty	k	1.98	3.18%

Table 22: Sunshine Pyranometer: Global Calibration with Reference Pyrheliometer with Shaded Pyranometer (Option B) Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Pyroheliometer & CMP(Diffuse)	B	42022	0.295%
Repeatability	Calibration Repeatability	A	3809	1.25%
DAS	Mux Box (ref)	A	56	0.0746%
DAS	Campbell Sci CR3000 (ref)	B	100	0.0374%
Reproducibilty	Calibration Reproducibility	A	9	0.785%
Repeatability	Sensor Repeatability	A	348	0.707%
Combined	Calibration Combined Uncertainty	eff	107	1.50%
Expanded	Calibration Expanded Uncertainty	k	1.98	2.98%

CAVEAT: The SPN1 has seven thermopile sensors and utilizes an internally programmed algorithm to interpret the analogue signals to global and diffuse radiation. The output is then a digital signal of calculated energy. Because we do not have the ability to use the output of the seven signals nor have the algorithm, an averaged measurement is calibrated and assessed in this analysis. Additionally, the reproducibility and calibration repeatability calibrations used for this analysis had a few issues. The program has gone through several revisions through learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Also, the calibration with references of the pyrheliometer with shaded pyranometer (Option B) has not been utilized for an extended period of time to allow for extensive uncertainty testing. Therefore, only the uncertainty of the truth (NREL calibration uncertainties) and DAS components of uncertainty are fully assessed, while sensor repeatability, calibration repeatability and reproducibility values are taken from the pyranometer calibration (Option A) assuming the Option B would result in the same or better uncertainties. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The CMP22s and CHP1 by Kipp and Zonen are calibrated at NREL annually against their standards which are traceable to the World Radiometric Reference (WRR) and World Infrared Standard Group (WISG). The calibration occurs outdoors against a pyrheliometer and shading disk for reference diffuse installed on solar trackers. The expanded uncertainty from NREL for the pyranometers using the spline interpolation (which is utilized in CVAL's program) is 1.28% and for the pyrheliometer is 0.66% all with a coverage factor of 1.96. Additionally, the zenith angle is a component of the calculations and CVAL acquires zenith angle data from NREL's solar position algorithm which has an uncertainty of ±0.0003° (Reda and Andreas, 2004).

CALIBRATION REPEATABILITY: Calibration data from 40 calibrations were used in the calibration repeatability determination. The difference between the calculated reference and the SPN1's calibrated shortwave radiation was used to calculate this uncertainty. The calibration repeatability from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for only the reference. Voltage was tested with a fluke precision voltage source at 20 mV and resulted in an uncertainty of 4.5 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below. Because the UUTs are a digital signal, no additional uncertainty is analyzed for the sensor and is assumed to be inclusive.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. Only the reference/s are assessed for analog signal uncertainty since the UUTs have a digital signal.

CALIBRATION REPRODUCIBILITY: A single sensor was evaluated for reproducibility over nine different calibration periods. These span three months, so the seasonal component was not fully captured. The calibrations occurred in May to July. The standard deviation of the predicted shortwave radiation of one sensor was used for this term. The reproducibility from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

SENSOR REPEATABILITY: Repeatability was tested indoors with a LED light source which provides a stable radiation source for signal repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 23. Table 24 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 23: Document Traceability for the Sunshine Pyranometer: Global Sensor Calibrations.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6041.pdf	CR3000
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Global
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Diffuse
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CHP1

Table 24: Requirements for the Sunshine Pyranometer: Global Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1006	NEON shortwave radiation sensors shall be calibrated to ± 6 W/meter^2 for primary sensors and ± 10 W/meter^2 for secondary sensors.

12 SUNSHINE PYRANOMETER: DIFFUSE (SPN1; DELTA-T; CAMBRIDGE, UK)

FIXTURE #: L2R500

NEON PART #: CA00180000

CALIBRATION DESCRIPTION: Up to eight sensors (with expansion capability for sixteen) are calibrated outdoors at CVALLA during clear day-time sky conditions. The reference for the calibration is a shaded pyranometer (CMP22; Kipp & Zonen; Delft, Netherlands) located on a sun tracker (SOLYS2; Kipp & Zonen), which is used to measure the diffuse shortwave radiation. Data is parsed for clear sky conditions and cleaned for outliers, which provides for quality calibration data. For more information on the calibration, see NEON.DOC.000794. The uncertainty evaluation resulted in Y = y ± 9.43% with 95% level of confidence. Values can be seen in Table 25 with details of the evaluation below.

Table 25: Sunshine Pyranometer: Diffuse Calibration with Reference Shaded Pyranometer Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	CMP22 (Diffuse)	B	319749	0.65%
Repeatability	Calibration Repeatability	A	9978	3.37%
DAS	Mux Box (ref)	A	56	0.626%
DAS	Campbell Sci CR3000 (ref)	B	100	0.174%
Reproducibilty	Calibration Reproducibility	A	9	3.09%
Repeatability	Sensor Repeatability	A	348	1.47%
Combined	Calibration Combined Uncertainty	eff	41	4.67%
Expanded	Calibration Expanded Uncertainty	k	2.02	9.43%

CAVEAT: The SPN1 has seven thermopile sensors and utilizes an internally programmed algorithm to interpret the analogue signals to global and diffuse radiation. The output is then a digital signal of calculated energy. Because we do not have the ability to use the output of the seven signals nor have the algorithm, an averaged measurement is calibrated and assessed in this analysis. Additionally, the reproducibility and calibration repeatability calibrations used for this analysis had a few issues. The program has gone through several revisions through learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Also, the calibration with references of the pyrheliometer with shaded pyranometer (Option B) has not been utilized for an extended period of time to allow for extensive uncertainty testing. Therefore, only the uncertainty of the truth (NREL calibration uncertainties) and DAS components of uncertainty are fully assessed, while sensor repeatability, calibration repeatability and reproducibility values are taken from the pyranometer calibration (Option A) assuming the Option B would result in the same or better uncertainties. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The CMP22s and CHP1 by Kipp and Zonen are calibrated at NREL annually against their standards which are traceable to the World Radiometric Reference (WRR) and World Infrared Standard

Group (WISG). The calibration occurs outdoors against a pyrheliometer and shading disk for reference diffuse installed on solar trackers. The expanded uncertainty from NREL for the pyranometers using the spline interpolation (which is utilized in CVAL's program) is 1.28% and for the pyrheliometer is 0.66% all with a coverage factor of 1.96. Additionally, the zenith angle is a component of the calculations and CVAL acquires zenith angle data from NREL's solar position algorithm which has an uncertainty of ±0.0003° (Reda and Andreas, 2004).

CALIBRATION REPEATABILITY: Calibration data from 40 calibrations were used in the calibration repeatability determination. The difference between the calculated reference and the SPN1's calibrated shortwave radiation was used to calculate this uncertainty. The calibration repeatability from the Option A calibration analysis was assumed to be the same in the case of reference Option B because of lack of data available and that Option B is a more accurate calibration method.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for only the reference. Voltage was tested with a fluke precision voltage source at 20 mV and resulted in an uncertainty of 4.5 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below. Because the UUTs are a digital signal, no additional uncertainty is analyzed for the sensor and is assumed to be inclusive.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. Only the reference/s are assessed for analog signal uncertainty since the UUTs have a digital signal.

CALIBRATION REPRODUCIBILITY: A single sensor was evaluated for reproducibility over nine different calibration periods. These span three months, so the seasonal component was not fully captured. The calibrations occurred in May to July. The standard deviation of the predicted shortwave radiation of one sensor was used for this term.

SENSOR REPEATABILITY: Repeatability was tested indoors with a Labsphere source which provides a stable radiation source for signal repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 26. Table 27 provides an outline of the relevant requirements as they apply to the calibration. All requirements are being met for the calibration.

Table 26: Document Traceability for the Sunshine Pyranometer: Diffuse Sensor Calibrations.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6041.pdf	CR3000
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kipp & Zonen	BORCAL 2014-01 CPM22_110247_130477_130478 SPN1_A627 CHP1_131069.pdf	CMP22 Diffuse

Table 27: Requirements for the Sunshine Pyranometer: Diffuse Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.3.1023	Sensors for diffuse radiation shall be calibrated prior to deployment and at least annually with a modified shade/unshade method (ASTM G167-05).
NEON.CVAL.4.1009	Diffuse radiation sensors shall be calibrated to ± 10 W/meter^2.
NEON.CVAL.4.1006	NEON shortwave radiation sensors shall be calibrated to ± 6 W/meter^2 for primary sensors and ± 10 W/meter^2 for secondary sensors.

13 LINE QUANTUM PAR (LI-191; LI-COR; LINCOLN, NE)

FIXTURE #: L2R600

NEON PART #: 0323440000

CALIBRATION DESCRIPTION: Up to sixteen sensors are calibrated outdoors at CVALLA during clear day-time sky conditions. The reference for the calibration are six PAR sensors (PQS1; Kipp & Zonen; Delft, Netherlands) spanning the meter of photodiode. Data is parsed for clear sky conditions and cleaned for outliers, which provides for quality calibration data. For more information on the calibration, see NEON.DOC.000752. The uncertainty evaluation resulted in Y = y ± 4.78% with 95% level of confidence. Values can be seen in Table 28 with details of the evaluation below.

Table 28: Line Quantum PAR Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	PQS1	B	636	1.67%
Repeatability	Calibration Repeatability	A	4514	1.29%
DAS	Mux Box (UUT)	A	230	0.080%
DAS	Mux Box (ref)	A	230	0.073%
DAS	Campbell Sci CR3000 (UUT)	B	100	0.036%
DAS	Campbell Sci CR3000 (ref)	B	100	0.034%
Reproducibilty	Calibration Reproducibility	A	12	1.052%
Repeatability	Standard Repeatability of the Mean	A	6	0.534%
Repeatability	Sensor Repeatability	A	307	0.144%
Combined	Calibration Combined Uncertainty	eff	246	2.42%
Expanded	Calibration Expanded Uncertainty	k	1.97	4.78%

CAVEAT: The reproducibility and repeatability calibrations used for this analysis had a few issues. The program has gone through several revisions through learnings of the outdoor calibration, and seasonal evaluation has not been taken fully into account/controlled. Future testing will aim to address these issues and uncertainty will likely improve as consistency in the fixture is maintained.

TRUTH: The previous year (8/2013 – 8/2014) utilized 12 PQS1s equally positioned the meter length of the sensing area. The coming year, 6 PQS1s will be equally positioned the length of the sensor. An uncertainty analysis was made and found little impact on uncertainty during 3 different events with 3 sets of standards. The PQS1s are calibrated in the PAR primary calibration fixture whose uncertainty is outlined in section 14 of this document.

CALIBRATION REPEATABILITY: Calibration data from 72 calibrations were used in the calibration repeatability determination. The difference between the averaged references and the LI-191 calculated

PAR was used to calculate this uncertainty. The maximum found for the 72 calibration was used and will be used for an automated QAQC check.

MUX BOX: The uncertainty resulting from the multiplexer and cables in the data acquisition system was assessed for both the UUT and reference. Though there are 6 or 12 reference sensors, because these resulting signals are averaged, it is assumed the averaged affect would be equivalent to one sensor. However, the worst case of 12 reference sensors was used. Voltage was tested with a fluke precision voltage source at 20 mV and resulted in an uncertainty of 7.1 µV. Contributing uncertainties include repeatability of the measurement on one port, reproducibility over all ports, and calibration repeatability in how close the reading from the box is to the direct measurement from the data logger. The truth contributing uncertainty is provided by the DAS below.

DAS: The uncertainty for the DAS was acquired from the data logger manual (Campbell Scientific, 2007). The quoted accuracy was converted to uncertainty by assuming normal distribution (dividing accuracy by 3). Relevant settings for determining offset and accuracy were operating temperatures of -25 to 50°C, offset with input reversal which provides half the basic resolution for the offset resolution of the differential. In this case, both the UUT and references are assessed for analog signal uncertainty signal.

CALIBRATION REPRODUCIBILITY: Three sensors were evaluated for reproducibility over twelve different calibration periods. These span three months, so the seasonal component was not fully captured. The calibrations occurred in March to June. The worst case of the three sensor's reproducibility was used.

STANDARD REPEATABILITY OF THE MEAN: The LI-191 calibration is a special case where the average of 6 sensors are taken over the 1 meter distance of the LI-191, so the variation seen crossed the 6 sensors is intrinsic in the measurement because it is essentially an averaging of the energy over the meter length. Therefore, this uncertainty is captured with the 6 sensors.

SENSOR REPEATABILITY: Repeatability was tested indoors with a LED source which provides a stable radiation source for signal repeatability. An Agilent 34410A 6.5 digit precision DMM (which is equivalent or higher precision than the CR3000) was used for data collection.

TRACEABILITY: All documents for the standards were located with details in Table 26. Table 27 provides an outline of the relevant requirements as they apply to the calibration. NEON.CVAL.4.1013 is unrealistic for the sensor type as the manufacturer quotes an accuracy of 10%. For NEON.CVAL.4.1011, the NIR and UV corrections are taken into account in the primary standard through Kipp and Zonen characterized spectral response of each of the standards (see NEON.DOC.000800 for more information on the correction); therefore, this should be accounted for in the transfer of standard.

Table 29: Document Traceability for the Line Quantum PAR Sensor Calibrations.

Location:	File Name:	Description:
\\neon.local\cvl\CalibrationData\L1R1000000\TS	Asset_WO#_CALID.xml	Calibraiton files for transfer of standards
N:\DEPT\CVL\Manufacturer Calibration Certificates\Campbell Scientific\CR 3000	Campbell Scientific_CR3000_Serial Number 6043.pdf	Campbell Scientific CR3000 Cal Cert

Table 30: Requirements for the Line Quantum PAR Sensor Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.4.1010	The sensor calibration shall be adjusted to account for differences between the lamp irradiance and the standard (ISO 9845-1) solar spectrum for the wavelength range of 400 to 700 nm.
NEON.CVAL.4.1011	The sensitivity of the PPFD sensor to near infra-red and ultra-violet radiation shall be tested using an appropriate filters.
NEON.CVAL.4.1013	Line quanta sensors PPFD sensors shall be calibrated to ±5 µm meter-2 second-1.

14 PAR PRIMARY (PQS1; KIPP & ZONEN; DELFT, NETHERLANDS)

FIXTURE #: L1R100

NEON PART #: CA00130000

CALIBRATION DESCRIPTION: PQS1 sensors are calibrated on a 1000 W quartz-halogen lamp that has been characterized and is traceable to NIST. Once calibrated on this fixture, the PQS1 sensors then transfer the standard to either the secondary calibration fixture for the LI-191 or PAR secondary fixture covered in this document in sections 12 and 14, respectively. Any amount of sensors can be calibrated in batches on the fixture and generally takes 30 minutes for 12 sensors. For more information on the calibration, see NEON.DOC.000742. The uncertainty evaluation resulted in Y = y ± 3.29% with 95% level of confidence. Values can be seen in Table 31 with details of the evaluation below.

Table 31: PAR Primary Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	NIST Lamp	B	100	0.40%
Repeatability	Calibration Repeatabiity	A	1502	1.46%
DAS	CVAL NI DMM ED4305 PXI-4071	B	100	0.550%
Reproducibilty	Calibration Reproducibility	A	6	0.449%
Repeatability	Sensor Repeatability	A	300	0.0895%
Combined	Calibration Combined Uncertainty	eff	636	1.67%
Expanded	Calibration Expanded Uncertainty	k	1.96	3.29%

TRUTH: A 1000 W quartz-halogen lamp is calibrated by NIST as a standard with a spectroradiometer which provides spectral irradiance values at wavelengths spanning the range of 350 to 800 nm (NIST, 2011). A polynomial is then fit to the spectral irradiance and an integration factor is developed from this function to relate the NIST lamp to solar spectral irradiance characterized by ASTM G 173-03 (ASTM, 2008). Corrections on the integration factor were developed based on a publication by Ross and Sulev (2000) in which they describe ways to reduce errors in PAR measurements through calibration. For the correction, an averaged spectral response from the PQS1s as determined by Kipp & Zonen was used. See the calibration manual for detailed calculations. The uncertainty from the NIST calibration is detailed at the various wavelengths, so the uncertainty was calculated by integrating these uncertainties over the wavelengths of 400 to 700. The uncertainty due to the spectral response differences in the PQS1s is accounted for in the calibration repeatability.

CALIBRATION REPEATABILITY: Because the truth is not an active reading (a previously characterized value), the average of a population of sensors is used as the truth when calculating calibration repeatability. Because the average spectral response of a population of sensors was used to develop the integration factor, calibration repeatability captures the worst case difference between the average spectral response and a single sensor's spectral response. These spectral response differences cause systematic errors that occur when integrating from an artificial light source (in this case, the NIST lamp) to sun spectral irradiance. Calibration data from 16 sensors and a clear sky day was used to determine calibration repeatability. The difference between the averaged PQS1s and the individual PQS1 was used to calculate this uncertainty. The maximum found for the 16 sensors was used.

DAS: The uncertainty for the DAS was acquired from the data logger manual (National Instruments, 2008). The values for accuracy were taken assuming the calibration is within 2 years for 100 mV range and T_{cal} ± 1 °C.

CALIBRATION REPRODUCIBILITY: Three sensors were evaluated for reproducibility over five different calibration events. The worst case of the three sensor's reproducibility was used.

SENSOR REPEATABILITY: Repeatability was tested by elongating the calibration for 6 sensors on a test lamp. The worst case was taken and reported in terms of percentage of reading.

TRACEABILITY: All documents for the standards were located with details in Table 32. However, the DMM for the shunt resistor (PCI-4065) has not been captured in the XML files as a standard. XML files from 2/28/14 through present should have the asset tag 21000000051498 as part of the calibration standards. Table 33 provides an outline of the relevant requirements as they apply to the calibration. Presently requirement NEON.CVAL.4.1011 is not being upheld. For NEON.CVAL.4.1011, the NIR and UV corrections are taken into account in the primary standard through Kipp and Zonen characterized spectral response of each of the standards (see NEON.DOC.000800 for more information on the correction).

Table 32: Document Traceability for the PAR Primary Calibrations.

Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Osram	Osram Sylvania 1000W Lamp_Serial Number F-642.pdf	NEON's NIST Lamp F-642
N:\DEPT\CVL\Manufacturer Calibration Certificates\Phillips	Philips, #FEL, 1000W Tungsten Quartz Halogen Lamp, SN F-658.pdf	NEON's NIST Lamp F-658
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	National Instruments_PXI-4071_Serial Number 181890F_2014.pdf	DMM Primary Fixture Cal Cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PCI 4065	National Instruments_PCI-4065_Serial Number EE7559_2014.pdf	DMM Shunt Resistor PCI4065
N:\DEPT\CVL\Manufacturer Calibration Certificates\Ohm Labs	CS-10 Current Shunt SN 14001.pdf	Primary shunt resistor (power supply traceability)
N:\DEPT\CVL\Manufacturer Calibration Certificates\Ohm Labs	CS-10 Current Shunt SN 14002.pdf	Primary shunt resistor (power supply traceability)

Table 33: Requirements for the PAR Primary Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment.
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques.
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations.
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques .
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1010	The sensor calibration shall be adjusted to account for differences between the lamp irradiance and the standard (ISO 9845-1) solar spectrum for the wavelength range of 400 to 700 nm.
NEON.CVAL.4.1011	The sensitivity of the PPFD sensor to near infra-red and ultra-violet radiation shall be tested using an appropriate filters.
NEON.CVAL.4.1012	PPFD sensors shall be calibrated to 5% of reading

15 PAR SECONDARY (PQS1; KIPP & ZONEN; DELFT, NETHERLANDS)

FIXTURE #: L1R200

NEON PART #: CA00130000

CALIBRATION DESCRIPTION: PQS1 sensors are calibrated on a secondary artificial light source fixture for high throughput. The light is set to 10 times the energy of the NIST lamp with a transfer of standard sensor that has been calibrated on the primary fixture. Any amount of sensors can be calibrated in batches on the fixture and generally takes 30 minutes for 12 sensors. For more information on the calibration, see NEON.DOC.000743. The uncertainty evaluation resulted in Y = y ± 4.99% with 95% level of confidence. Values can be seen in Table 34 with details of the evaluation below.

Table 34: PAR Secondary Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	PQS1 TOS	B	636	1.67%
Repeatability	Calibration Repeatabiity	A	1572	1.77%
DAS	CVAL NI DMM 187C56A PXI-4071	B	100	0.114%
Reproducibilty	Calibration Reproducibility	A	7	0.729%
Repeatability	Sensor Repeatability	A	10	0.0241%
Combined	Calibration Combined Uncertainty	eff	637	2.54%
Expanded	Calibration Expanded Uncertainty	k	1.96	4.99%

TRUTH: The energy as read by the transfer of standard sensor is essentially what provides the truth. The energy is modified by a power supply to be 10 times the intensity of the NIST lamp. The calibration coefficients for the UUTs are then calculated from this energy.

CALIBRATION REPEATABILITY: Because the truth is not taken simultaneously with the UUT and the spectral differences that may occur between TOS and UUT, the calibration repeatability is determined from the outdoor validation. A follow up validation outdoors is performed with a TOS sensor versus the UUTs. For more information about this process, see NEON.DOC.000748. The calibration repeatability was the last uncertainty to be determined and is used as a QAQC check. The value was determined by meeting the 5% requirement. Therefore, sensors that do not meet that calibration repeatability are failed for QAQC and are not deployed.

DAS: The uncertainty for the DAS was acquired from the data logger manual (National Instruments, 2008). The values for uncertainty were taken with assuming the calibration is within 2 years for 100 mV range and T_{cal} ± 1 °C.

CALIBRATION REPRODUCIBILITY: Three sensors were evaluated for reproducibility and one sensor with seven different calibration events was used for determination of the standard deviation.

SENSOR REPEATABILITY: Repeatability was tested by elongating the calibration for 25 sensors. The worst case was taken and reported in terms of percentage of reading.

TRACEABILITY: All documents for the standards were located with details in Table 35. Table 36 provides an outline of the relevant requirements as they apply to the calibration. Presently requirements NEON.CVAL.4.1011, 1012, and 1049 are not being upheld. NEON.CVAL.4.1012 was supposed to be modified to 5% as the current requirement is unattainable for the sensor type. For NEON.CVAL.4.1011, the NIR and UV corrections are taken into account in the primary standard through Kipp and Zonen characterized spectral response of each of the standards (see NEON.DOC.000800 for more information on the correction); therefore, this should be accounted for in the transfer of standard. NEON.CVAL.1049 is not presently able to be upheld due to lack of information of sensor tracking outside CVAL (i.e. we do not have systems in place to control where the sensor goes after CVAL).

Table 35: Document Traceability for the PAR Secondary Calibrations.

Location:	File Name:	Description:
\\neon.local\cvl\CalibrationData\L1R1000000\TS	Asset_WO#_CALID.xml	Calibraiton files for transfer of standards
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	NationalInstruments_PXI-4071_SerialNumber 187C56A_2014.pdf	DMM Primary Fixture Cal Cert

Table 36: Requirements for the PAR Secondary Calibrations.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment.
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques.
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations.
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques .
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1010	The sensor calibration shall be adjusted to account for differences between the lamp irradiance and the standard (ISO 9845-1) solar spectrum for the wavelength range of 400 to 700 nm.
NEON.CVAL.4.1011	The sensitivity of the PPFD sensor to near infra-red and ultra-violet radiation shall be tested using an appropriate filters.
NEON.CVAL.4.1012	PPFD sensors shall be calibrated to ± 2.5 µm m-2 s-1.
NEON.CVAL.4.1049	The response of each grouping of PAR (i.e., along an individual tower profile) shall be validated to ± 15 µmol meters^-2 second^-1 (among sensors) against a recognized standard using field transfer standard; the definition of sensor grouping is all sensors deployed at a site together.

16 GRAPE DATA ACQUISITION SYSTEM (NEON; BOULDER)

FIXTURE #: L1D100

NEON PART #: CB14023600 (merlot) and CB14043600 (concord)

CALIBRATION DESCRIPTION: Calibrations for resistance and voltage occur at 23°C and at 100 and 1000 Ω and 0.5 and 0.01 V characterizations, respectively. The resistance calibration characterizes two internal precision resistors that are used continually for calculation of the data acquisition which more precisely define temperature response of the system. The voltage is also taken through a temperature characterization at 0.5 V at temperatures of 50, 40, 30, 0, -20, -30 °C. The temperature characterization and precision resistor is GRAPE specific and applies to all channels while the voltage calibration is channel specific. The capacity for the two DAQ racks is 32 UUTs, with one spot generally reserved for a repeating gold standard. For more information on the calibration, see NEON.DOC.000754. The uncertainty evaluation resulted in Y = y ± (0.0385% of reading + 0.0067 Ω) for resistance and Y = y ± (0.0734% of reading + $2.0*10^{-6}$ V) for voltage with 95% level of confidence. Values can be seen in Table 37 and 38 for resistance and voltage, respectively, with details of the evaluation below.

Table 37: GRAPE Resistance Calibration Uncertainty Estimation 2014.

		Type of Assessment	**n/Deg of Freedom**	**Uncertainty**
Truth	Agilent 3458A (%)	B	100	0.00040%
Repeatability	Calibration Repeatability (%)	A	1289	0.014%
Reproducibilty	Calibration Reproducibility (%)	A	30	0.013%
Repeatability	Sensor Repeatability (%)	A	240	0.0023%
Combined	Calibration Combined Uncertainty (%)	eff	139	0.0195%
Expanded	Calibratino Expanded Uncertainty (%)	k	1.98	0.0385%
Offset	Uncertainty (Ω)			0.0067

Table 38: GRAPE Voltage Calibration Uncertainty Estimation 2014.

		Type of Assessment	**n/Deg of Freedom**	**Uncertainty**
Truth	Agilent 3458A (%)	B	100	0.0013%
Repeatability	Calibration Repeatability (%)	A	1289	0.034%
Reproducibilty	Calibration Reproducibility (%)	A	30	0.016%
Repeatability	Sensor Repeatability (%)	A	240	0.0100%
Combined	Calibration Combined Uncertainty (%)	eff	596	0.0374%
Expanded	Calibratino Expanded Uncertainty (%)	k	1.96	0.0734%
Offset	Uncertainty (V)			2.0E-06

TRUTH: The Agilent 3458 DMM reads the same source as is delivered to the Grape and provides the truth for the analogue signals. Values were acquired from Agilent (2011) spec sheet, and 1 year factor calibration values were taken for accuracy estimations as CVAL calibrates all standards annually. Additionally, it was assumed that auto calibration was properly executed as ACAL should be on and run before every calibration. Further, ambient temperatures are assumed to be ± 1°C from ACAL ± 5°C from TCAL. All ambient temperatures for the calibrations are logged and can be verified for these assumptions. Accuracy was converted to uncertainty assuming a normal distribution (divided by 3).

CALIBRATION REPEATABILITY: Calibration data from 26 UUTs during the month of August were evaluated for calibration repeatability. The value is calculated from the difference between each signal channel and the Agilent DMM reading from the validation data. Validation of resistance occurs at 80, 100, 120, and 1000 Ω and for voltage at 0.01, 0.1, and 1 V. Validations occur over the temperature range of 50 to -30. Worst case relative uncertainties for the given test points were taken and the worst case over the 6 channels of the 26 UUTs was used to represent this uncertainty.

CALIBRATION REPRODUCIBILITY: One grape was evaluated for reproducibility over 30 different calibrations. Worst cases for voltage and resistance at 0.01 V and 10 Ω relative uncertainties of the 6 channels were used.

SENSOR REPEATABILITY: Repeatability was tested on seven UUTs and 6 channels on the two different DAQ racks. 240 data points were taken at 80, 100, 120, and 1000 Ω and 0.01, 0.1, and 1 V. Worst case repeatability at those test points and amongst all the channels was taken for repeatability.

OFFSET: The offsets were determined by shorting the signal and taking 240 data points at this zero reading for seven UUTs and 6 channels. The signal was normalized to the reading of the truth, so the difference between UUT and truth was taken as the zero reading and averaged over the 240 data points. The worst case of all the channels was taken for the offset.

TRACEABILITY: All documents for the standards were located with details in Table 39. The Agilent DMMs were coming due for calibration at the time of this evaluation and proper actions were in place to update the standards' calibrations. Table 40 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 39: Document Traceability for the Grape Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Agilent\3458A Digital Multimeter	Agilent Tech., 3458A, Digital Multimeter_Serial Number MY45049459_2013.pdf	Agilent DMM 3458A
N:\DEPT\CVL\Manufacturer Calibration Certificates\Agilent\3458A Digital Multimeter	Agilent Tech., 3458A, Digital Multimeter_Serial Number MY45049386_2013.pdf	Agilent DMM 3458A
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5720A Multifunction Calibrator	Fluke 5720A, MultiFunction Calibrator, serial number 2353202_2014.pdf	Fluke 5720A
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5720A Multifunction Calibrator	Fluke 5720A, MultiFunction Calibrator, serial number 2372210_2014.pdf	Fluke 5720A

Table 40: Requirements for the Grape Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.

17 HUMIDITY SENSOR - HUMIDITY (HMP155; VAISALA; LOUISVILLE, CO)

FIXTURE #: L1W100

NEON PART #: CA04430000

CALIBRATION DESCRIPTION: The HMP is placed in a Dew-Point Hygrometer or chilled mirror to provide a chamber for controlled RH and temperature. The chamber is cycled through two points for humidity at a controlled temperature and then validated at various temperature and humidity combinations. Because the sensor coefficients are internally calculated, the sensor calibration data includes as received and as left data. For more information on the calibration, see NEON.DOC.001066. The uncertainty evaluation resulted in Y = y ± 2.2%RH with 95% level of confidence. Values can be seen in Table 41 with details of the evaluation below.

Table 41: Humidity Sensor - Humidity Calibration Uncertainty Estimation 2014.

All Uncertainties given in % RH		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Chilled Mirror	B	100	0.13%
Conversion	Truth Conversion	B	100	0.23%
Repeatability	Measurement Repeatability	A	70	0.82%
Reproducibility	Calibration Reproducibility	A	10	0.66%
Repeatability	Sensor Repeatability	A	308	0.00582%
Combined	Calibration Combined Uncertainty	eff	50	1.1%
Expanded	Calibration Expanded Uncertainty	k	2.01	2.2%

TRUTH: The Dew-Point Hygrometer was calibrated at NIST against air of a known water vapor content, generated by NIST Hybrid Humidity Generator. The quoted uncertainty for the calibration is 0.05°C with a coverage factor of 2. By utilizing a simple conversion covered by Lawrence (2005) and seen in Equation 17, the dewpoint and chamber temperature readings used to convert to RH are derived to approximate the uncertainty of RH as seen in Equation 18.

$$\%R = (100 - 5(t - t_d)) \quad (17)$$

$$U_R = \sqrt{(5u_t)^2 + \left(5u_{t_d}\right)^2} \quad (18)$$

TRUTH CONVERSION: Using the output from the hygrometer and the chamber ambient temperature, the RH is calculated by the following equations:

$$\%R = 100 * {}^{e_t}/_{e_s} \quad (19)$$

$$e_s = C_1 e \quad \left(\frac{A_1 t}{B_1 + t}\right) \tag{20}$$

$$e_t = C_1 e \quad \left(\frac{A_1 t_d}{B_1 + t_d}\right) \tag{21}$$

Where A_1 = 17.625, B_1 =243.04°C, and C_1 = 610.94 Pa.

Based on approximations by Lawrence, 2005, this relationship has an uncertainty of 0.23%RH.

CALIBRATION REPEATABILITY: Calibration repeatability was calculated from validation data that is taken post calibration. Temperatures and RHs are varied for this test and include RH of 11, 20, 50, and 73%. The maximum calibration repeatability was used from 7 to 11 runs for 5 different sensors each.

CALIBRATION REPRODUCIBILITY: Reproducibility was tested for 3 sensors with 10 runs. The maximum standard deviation between the predicted RHs from the resulting calibration coefficients from 10 reproduced calibrations was used.

SENSOR REPEATABILITY: One sensor was held at constant set points of 11, 23, and 73 for 308 readings and the maximum repeatability of these readings was taken.

TRACEABILITY: All documents for the standards were located with details in Table 42. Table 43 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirements, they may not be achievable. Vaisala quotes a sensor accuracy of ±(1 + 0.8% of reading) %RH and an uncertainty of the calibration of ±1% RH. Combining those two terms in quadrature provides an uncertainty of ~2% at high RH readings. Additionally, pressure is not being controlled as mentioned in NEON.CVAL.3.1017. However, this was brought up in the design review and requirements were supposed to be modified to reflect the design implemented.

Table 42: Document Traceability for the Humidity Sensor - Humidity Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kahn	Kahn Optisure_Dew Point Hygrometer SN 141958.pdf	Chilled Mirror/Optical Hygrometer

Table 43: Requirements for the Humidity Sensor - Humidity Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1011	Air temperature sensors shall be calibrated to achieve a 0.1 °C accuracy.
NEON.CVAL.3.1017	Relative humidity sensors shall be calibrated prior to deployment and at a minimum annually in a controlled humidity chamber that has temperature and pressure control, (±0.1 °C and ±0.5 kPa, respectively).
NEON.CVAL.4.1003	The relative humidity calibration chamber shall be monitored by a NIST traceable water vapor standard (e.g. chilled mirror) that is accurate to ± 0.05 °C and has an integration time of less than 20 seconds.
NEON.CVAL.4.1004	Relative humidity sensors shall be calibrated to ±1.5% relative humidity.
NEON.CVAL.4.1005	The output of the dew point generator should be accurate to within ±0.2 °C.

18 HUMIDITY SENSOR - TEMPERATURE (HMP155; VAISALA; LOUISVILLE, CO)

FIXTURE #: L1W100

NEON PART #: CA04430000

CALIBRATION DESCRIPTION: The HMP is placed in a Dew-Point Hygrometer or chilled mirror to provide a chamber for controlled RH and temperature. The chamber is cycled through two points for temperature at a controlled humidity and then validated at various temperature and humidity combinations. Because the sensor coefficients are internally calculated, the sensor calibration data includes as received and as left data. For more information on the calibration, see NEON.DOC.001066. The uncertainty evaluation resulted in Y = y ± 0.19°C with 95% level of confidence. Values can be seen in Table 44 with details of the evaluation below.

Table 44: Humidity Sensor - Temperature Calibration Uncertainty Estimation 2014.

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	PRT	B	8	0.0049
Repeatability	Calibration Repeatability	A	80	0.072
DAQ	Omega (PRT Reading)	A	100	0.00026
Reproducibilty	Calibration Reproducibility	A	10	0.061
Repeatability	Sensor Repeatability	A	308	0.0041
Combined	Calibration Combined Uncertainty	eff	43	0.095
Expanded	Calibration Expanded Uncertainty	k	2.02	0.19

TRUTH: The analysis for the uncertainty of the PRT can be found in Section 5 of this document.

CALIBRATION REPEATABILITY: Calibration repeatability was calculated from validation data that is taken post calibration. Temperatures and RHs are varied for this test and include RH of 15, 23, and 40°C. The maximum calibration repeatability was used from 7 to 11 runs for 5 different sensors each.

DAQ: From the Transcat supplemental report, the uncertainty for cal process and measurement is provided at 100 ohms with a coverage factor of 2. Utilizing these two values and the derivation of the calibration coefficients from the PRT, the uncertainty was calculated for the max reading of 120 ohms or ~50°C.

CALIBRATION REPRODUCIBILITY: Reproducibility was tested for 3 sensors with 10 runs. The maximum standard deviation between the predicted RHs from the resulting calibration coefficients from 10 reproduced calibrations was used.

SENSOR REPEATABILITY: One sensor was held at constant set points of 11, 20, and 50 °C for 308 readings and the maximum repeatability of these readings was taken.

TRACEABILITY: All documents for the standards were located with details in Table 45. Table 46 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirements, they may not be achievable. Vaisala quotes a sensor accuracy of ± 0.25°C for the range of temperatures of -30°C to 50°C.

Table 45: Document Traceability for the Humidity Sensor - Temperature Calibration.

Current Location:	File Name:	Description:
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050946_WO1099_18776.xml	PRT
N:\DEPT\CVL\Manufacturer Calibration Certificates\Omega\PT-104A	Omega_PT104A_Temp Data logger SN CO120_107.pdf	Omega PT-104

Table 46: Requirements for the Humidity Sensor - Temperature Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1011	Air temperature sensors shall be calibrated to achieve a 0.1 °C accuracy.
NEON.CVAL.3.1017	Relative humidity sensors shall be calibrated prior to deployment and at a minimum annually in a controlled humidity chamber that has temperature and pressure control, (±0.1 °C and ±0.5 kPa, respectively).
NEON.CVAL.4.1003	The relative humidity calibration chamber shall be monitored by a NIST traceable water vapor standard (e.g. chilled mirror) that is accurate to ± 0.05 °C and has an integration time of less than 20 seconds.
NEON.CVAL.4.1004	Relative humidity sensors shall be calibrated to ±1.5% relative humidity.
NEON.CVAL.4.1005	The output of the dew point generator should be accurate to within ±0.2 °C.

19 AQUA/LEVEL TROLL - PRESSURE (200/500; IN_SITU INC.; FORT COLLINS, CO)

FIXTURE #: L1A300

NEON PART #: 0317730000 (aqua) and 0317680000 (level)

CALIBRATION DESCRIPTION: Pressure delivered to a pressure cell is controlled by the PPC4 – the truth for this calibration. The calibrator takes the cell through 4 different pressure set points (96.5, 68.9, 41.4, and 20.7 kPa) that were determined to provide the lowest uncertainty in combination. The pressure cell has eight ports centered around a state of health pressure gauge. For more information on the calibration, see NEON.DOC.002556. The uncertainty evaluation resulted in Y = y ± 0.29 kPa with 95% level of confidence. Values can be seen in Table 47 with details of the evaluation below.

Table 47: Aqua/Level Troll - Pressure Calibration Uncertainty Estimation 2014.

All Uncertainties given in kPa		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	PPC4	B	100	0.0098
Repeatability	Calibration Repeatability	A	400	0.007
Reproducibilty	Calibration Reproducibility	A	13	0.13
Repeatability	Sensor Repeatability	A	100	0.0109
Combined	Calibration Combined Uncertainty	eff	12	0.13
Expanded	Calibration Expanded Uncertainty	k	2.18	0.29

TRUTH: The PPC 4 technical note 8050TN11 (Bair, 2009) provides calculations for uncertainty. This uncertainty calculation considers operation mode, fluid media, environment, orientation, reference uncertainty, calibration frequency, auto-zero frequency, control precision, and dwell (short term stability) as sources. These uncertainties are calculated in real-time with the calibration and are described by Fluke as the “delivered” uncertainty.

CALIBRATION REPEATABILITY: The applied calibration coefficients vs the standard were evaluated for the calibration data from four sensors through 13 calibration runs. The worst case of these 52 calculated calibration repeatability metrics were used.

CALIBRATION REPRODUCIBILITY: Four sensors were evaluated for reproducibility of the calibration through 13 calibration runs. The sensors were modified through all eight positions of the pressurized cell and maintained in position for five and little difference was seen between the modified positions. The worst case standard deviation of the four sensors’ calibration reproducibility was taken. Note that there were four plugs in the other four positions at this time.

SENSOR REPEATABILITY: 100 measurements at each set point are taken during the calibration, the worst case standard deviation for the four set points and four sensors were used.

TRACEABILITY: All documents for the standards were located with details in Table 87. Table 88 provides an outline of the relevant requirements as they apply to the calibration. The 0.29 kPa uncertainty translates to approximately 0.33 cm, so depending on the translation of requirements, NEON.CVAL.4.1047 may not be currently achieved. However, improvements on the calibration may be possible to attain better reproducibility results.

Table 48: Document Traceability for the Aqua/Level Troll - Pressure Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\PPC4 Pressure Calibrator	Fluke, PPC4, Pressure Calibrator SN758_Oct2013.pdf	PPC4 calibration cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\PPC4 Pressure Calibrator	Fluke, PPC4, Pressure Calibrator SN1063.pdf	PPC4 calibration cert

Table 49: Requirements for the Aqua/Level Troll - Pressure Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1049	Sensors for well pressure used to calculate water depth in wells shall be calibrated prior to deployment and at least annually
NEON.CVAL.4.1047	Water depth sensors shall be calibrated to within ±0.1 cm of water.

20 AQUA TROLL - TEMPERATURE (200/500; IN_SITU INC.; FORT COLLINS, CO)

FIXTURE #: L1A300

NEON PART #: 0317730000 (aqua)

CALIBRATION DESCRIPTION: The calibration bath filled with DI water has 8 different ports centered around the SPRT which is the truth in this calibration. The SPRTs are calibrated in house with fixed cells consistent with ITS-90 standards. The bath is ramped through five set points (5, 10, 30, 45, 50°) which were determined in combination to have the lowest uncertainty. For more information on the calibration, see NEON.DOC.001276. The uncertainty evaluation resulted in Y = y ± 0.087°C with 95% level of confidence. Values can be seen in Table 50 with details of the evaluation below.

Table 50: Aqua Troll - Temperature Calibration Uncertainty Estimation 2014.

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	SPRT	B	100	0.00012
Repeatability	Calibration Repeatability	A	875	0.035
DAS	DMM for SPRT reading	B	100	0.000010
Reproducibilty	Calibration Reproducibility	A	14	0.027
Repeatability	Sensor Repeatability	A	125	0.018
Combined	Calibration Combined Uncertainty	eff	90	0.044
Expanded	Calibration Expanded Uncertainty	k	1.99	0.087

TRUTH: The SPRT Calibration is performed in house and follows the NIST Special Publication by Strouse (2008). In this document, the uncertainties are detailed as related with the calibration with the fixed point cells. Because the calibration performed by CVAL emulates these procedures, Type B evaluation was used from this published knowledge. However, in future, a Type A evaluation may be justified.

MESAUREMENT REPEATABILITY: Four sensors were run through the calibration 14 times modifying through the eight positions and holding constant for six calibrations. Calibration repeatability was calculated as the difference between the applied coefficient output of the UUT vs. the SPRT. The maximum of the 56 calculated metrics was used to represent calibration repeatability of the calibration and is used for auto QAQC checking.

DAS: The SPRT reading is wired directly into the PXI-4071 DMM. Uncertainty values from the following document National Instruments_PXI-4071_Serial Number EFEBC2.pdf were used as a Type B evaluation from a calibration certificate. The PXI-4071 used in the calibration goes through the same calibration as the one detailed in this document, so the uncertainties were considered the same. The associated resistance calibration point was the 1k Ohm for 4 wire resistance which is consistent with the fixture wiring set-up. The calibration coefficients for multiple sensors and the resistance range of 120 through 88 ohms which corresponds to 50 through -30°C were used to transform the uncertainty into °C using the partial derivative of the second order polynomial. Therefore the uncertainty follows Equation 12:

$$u(y\,^\circ C) = [2 * C \qquad 2 * (R) + C \qquad 1] * u(D \qquad ohm\ ) \tag{12}$$

where R is the resistance taken through 120 through 88, CVALA2 and CVALA1 are calibration coefficients for a given sensor and u(DAS ohms) is from the calibration certificate noted above.

CALIBRATION REPRODUCIBILITY: The standards deviation of the 14 runs with the four sensors was calculated and the maximum between the four sensors was used.

SENSOR REPEATABILITY: The calibration takes 125 readings at each setpoint. Therefore, the maximum standard deviation found for the four sensors through all calibrations was used.

TRACEABILITY: All documents for the standards were located with details in Table 87. Table 88 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 51: Document Traceability for the Aqua Troll - Temperature Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	National Instruments_PXI-4071_Serial Number ED4305_2014.pdf	DMM Cal Cert
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001183_WO1001_17048.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001182_WO1000_17046.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000051571_WO1002_17044.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050167_WO196_17042.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050166_WO195_17047.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050165_WO194_17043.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001184_WO955_17045.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050156_WO193_17049.xml	SPRT Calibration Files
N:\DEPT\CVL\QAQC\PRT	SPRT_Summary_2014.xlsx	SPRT Calibration History File

Table 52: Requirements for the Aqua Troll - Temperature Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1012	Soil and water temperature sensors shall be calibrated to achieve a 0.15 °C accuracy

21 AQUA TROLL - CONDUCTIVITY (200; IN_SITU INC.; FORT COLLINS, CO)

FIXTURE #: L1A300

NEON PART #: 0317730000

CALIBRATION DESCRIPTION: The calibration of the aquatroll utilizes conductivity solutions and a conductivity meter as the truth. The solutions used are 10, 50, 100, 500, and 1000 µS and up to 8 sensors can be put into the solution centered around the reference conductivity meter. For more information on the calibration, see NEON.DOC.002557. The uncertainty evaluation resulted in Y = y ± 0.731% with 95% level of confidence. Values can be seen in Table 53 with details of the evaluation below.

Table 53: Aqua Troll - Conductivity Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Conductivity Meter	B	100	0.231%
Repeatability	Calibration Repeatability	A	10	0.184%
Reproducibilty	Calibration Reproducibility	A	10	0.211%
Repeatability	Sensor Repeatability	A	10	0.266%
Combined	Calibration Combined Uncertainty	eff	46	0.363%
Expanded	Calibration Expanded Uncertainty	k	2.01	0.731%

TRUTH: The Fisher Scientific conductivity meter calibration certificate provides tolerance values of 0.4% of reading. When assuming a rectangular distribution for this tolerance metric, the uncertainty results in 0.231% of reading.

CALIBRATION REPEATABILITY: The difference between the meter and the UUT at a given set point was used to calculate calibration repeatability. Because 10 readings are taken for a given solution, 10 is the degrees of freedom for the calibration repeatability. Ten calibrations for five sensors were evaluated and the maximum of the 250 calculated calibration repeatability metrics was used.

REPRODUCIBILITY: The sensors were modified through the eight positions and repeated in the same position twice. The maximum reproducibility for the five sensors was used.

SENSOR REPEATABILITY: The calibration utilizes 10 readings for each set point to develop the fit. Therefore, the maximum found standard deviation for these 10 readings during the 10 calibrations of five sensors was used.

TRACEABILITY: All documents for the standards were located with details in Table 87. Table 88 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 54: Document Traceability for the Aqua Troll - Conductivity Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fisher Scientific	Fisher Scientific 09_330 Conductivity Meter SN 122447225_2014.pdf	Conductivity Meter Cal Cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fisher Scientific	Fisher Scientific 09-330 Conductivity meter SN 130385403.pdf	Conductivity Meter Cal Cert
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fisher Scientific	Fisher Scientific 09-330 Conductivity meter SN 130385407.pdf	Conductivity Meter Cal Cert

Table 55: Requirements for the Aqua Troll - Conductivity Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1045	Specific electrical conductance sensors shall be calibrated prior to deployment and at a minimum every year according to the procedures established by the USGS Techniques for Water Resources Investigations Field Manual.
NEON.CVAL.4.1043	The electrical conductance sensors shall be calibrated to within the following tolerances: ±5 percent for conductivity ≤100 µsiemens/cm; and ±3 percent for conductivity >100 µsiemens/cm.

22 SECONDARY PRECIPITATION - TIPPING BUCKET (10490 AND 10491; MET ONE INSTRUMENTS; GRANTS PASS, OR)

FIXTURE #: L1P200

NEON PART #: CD03710000 (non-heated - 10491) and CD03720000 (heated - 10490)

CALIBRATION DESCRIPTION: An Alicat flow meter both controls and measures the flow delivered to the calibration system. The water is then sent through the sensor to accumulate tips. If manual modification to the sensor is necessary (i.e. adjusting the stops of the tips), the calibration takes the operator through a series of adjustments. As received data is captured so as to provide any manual adjustment changes. An average tipping threshold for the sensor is then calculated based on the volume of water per tip. For more information on the calibration, see NEON.DOC.001212. The uncertainty evaluation resulted in Y = y ± 2.62% with 95% level of confidence. Values can be seen in Table 56 with details of the evaluation below.

Table 56: Secondary Precipitation Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Alicat Flowmeter	B	100	0.809%
Repeatability	Calibration Repeatability	A	11	0.468%
Reproducibilty	Calibration Reproducibility	A	8	0.305%
Repeatability	Sensor Repeatability	A	77	1.445%
Combined	Calibration Combined Uncertainty	eff	304	1.33%
Expanded	Calibration Expanded Uncertainty	k	1.97	2.62%

TRUTH: The quoted accuracy of the Alicat certification is 2% of full scale which is 50 ccm, so by taking the accuracy in ccm, dividing by 3 and dividing by the total flow, a percent uncertainty is attained.

CALIBRATION REPEATABILITY: The calibration repeatability in this case is a systematic effect. As a QAQC control, a tolerance of 0.15 mL is allowed for the difference between left bucket tip and right bucket tip. Therefore, the maximum uncertainty would be an odd number of tips. Because this is a systematic effect, the uncertainty is not added in quadrature, and is added to the other uncertainty terms after they have been added in quadrature for the combined uncertainty.

CALIBRATION REPRODUCIBILITY: The reproducibility was tested by not modifying the tipping stops. One UUT was evaluated due to time constraints.

SENSOR REPEATABILITY: Each calibration calculates the average volume of water per tip 77 times per bucket. Therefore, the repeatability was estimated from these tips.

TRACEABILITY: All documents for the standards were located with details in Table 87. Table 88 provides an outline of the relevant requirements as they apply to the calibration. The calibration utilizes a flow rate equivalent to 76.2 mm/hour , which 2.62% is ~2 mm/hour. Depending on the interpretation of the requirements, this may or may not meet NEON.CVAL.4.1040.

Table 57: Document Traceability for the Secondary Precipitation Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Alicat\LC 50CCM Flow Controller	Alicat Scientific_LC-50CCM-D-DB15 Liquid Flow Controller_Serial Number 90582_2014.pdf	Alicat Flow Controller

Table 58: Requirements for the Secondary Precipitation Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.4.1040	For secondary measurements, the accuracy for precipitation rate shall be calibrated to 2 mm/hour.

23 UNDERWATER QUANTUM PAR (LI-192; LI-COR; LINCOLN, NE)

FIXTURE #: L1A600

NEON PART #: 0320540000

CALIBRATION DESCRIPTION: The underwater quantum PAR sensors are calibrated on a secondary artificial light source fixture for high throughput. The light is set to 10 times the energy of the NIST lamp with a transfer of standard sensor that has been calibrated on the primary fixture. Any amount of sensors can be calibrated in batches on the fixture and generally takes 30 minutes for 12 sensors. For more information on the calibration and validation, see documents NEON.DOC.000743 and NEON.DOC.000748, respectively. The uncertainty evaluation resulted in Y = y ± 5.40% with 95% level of confidence. Values can be seen in Table 59 with details of the evaluation below.

Table 59: Underwater Quantum PAR Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	PQS1 TOS	B	636	1.67%
Repeatability	Calibration Repeatability	A	1102	2.09%
DAS	CVAL NI DMM 187C56A PXI-4071	B	100	0.069%
Reproducibilty	Calibration Reproducibility	A	10	0.647%
Repeatability	Sensor Repeatability	A	10	0.0279%
Combined	Calibration Combined Uncertainty	eff	1171	2.75%
Expanded	Calibration Expanded Uncertainty	k	1.96	5.40%

TRUTH: The truth is the PQS1 sensor calibrated in the PAR primary calibration fixture whose uncertainty is outlined in section 14 of this document.

CALIBRATION REPEATABILITY: Calibration repeatability was evaluated outdoors at CVALLA with three sensors co-located with a standard. The data was parsed for clear sky/quality data. The maximum found for the three sensors was used for uncertainty.

CALIBRATION REPRODUCIBILITY: Each sensor was recalibrated on the secondary 10 times with the same standard and evaluated for reproducibility.

SENSOR REPEATABILITY: The average of 10 readings is used to develop to calibration coefficient. Therefore the standard deviation was derived to represent repeatability.

TRACEABILITY: All documents for the standards were located with details in Table 87. Table 88 provides an outline of the relevant requirements as they apply to the calibration. Presently requirements NEON.CVAL.4.1011, 1012, and 1049 are not being upheld. NEON.CVAL.4.1012 was supposed to be modified to 5% as the current requirement is unattainable for the sensor type. For NEON.CVAL.4.1011, the NIR and UV corrections are taken into account in the primary standard through Kipp and Zonen characterized spectral response of each of the standards (see NEON.DOC.000800 for more information on the correction); therefore, this should be accounted for in the transfer of standard. NEON.CVAL.1049 is not presently able to be upheld due to lack of information of sensor tracking outside CVAL (i.e. we do not have systems in place to control where the sensor goes after CVAL).

Table 60: Document Traceability for the Underwater Quantum PAR Calibration.

Location:	File Name:	Description:
\\neon.local\cvl\CalibrationData\L1R1000000\TS	Asset_WO#_CALID.xml	Calibraiton files for transfer of standards
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	NationalInstruments_PXI-4071_SerialNumber 187C56A_2014.pdf	DMM Primary Fixture Cal Cert

Table 61: Requirements for the Underwater Quantum PAR Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment.
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques.
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations.
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques .
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters
NEON.CVAL.3.1020	Shortwave radiation sensors shall be calibrated prior to deployment and at least annually against precision pyranometers following protocols established by the Baseline Surface Radiation Network, World Radiation Monitoring Center, and NOAA-Global Monitoring Division SURFRAD program.
NEON.CVAL.4.1010	The sensor calibration shall be adjusted to account for differences between the lamp irradiance and the standard (ISO 9845-1) solar spectrum for the wavelength range of 400 to 700 nm.
NEON.CVAL.4.1011	The sensitivity of the PPFD sensor to near infra-red and ultra-violet radiation shall be tested using an appropriate filters.
NEON.CVAL.4.1012	PPFD sensors shall be calibrated to ± 2.5 µm m-2 s-1.
NEON.CVAL.4.1049	The response of each grouping of PAR (i.e., along an individual tower profile) shall be validated to ± 15 µmol meters^-2 second^-1 (among sensors) against a recognized standard using field transfer standard; the definition of sensor grouping is all sensors deployed at a site together.

24 ISOTOPIC WATER COMPOSITION - $\delta^{18}O$-(H_2O) (L2130; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1W200

NEON PART #: 0328050000

CALIBRATION DESCRIPTION: The calibration of the L2130 includes a water channel calibration followed by the secondary standards traceable to IAEA being sent through the analyzer. Secondary standards have been analyzed by INSTARR for isotopic water composition and uncertainty. The analyzer takes 10 readings and the last 3 of those reading are used for the calibration fit. For more information on the calibration, see NEON.DOC.002422. The uncertainty evaluation resulted in Y = y ± 0.29 ‰ with 95% level of confidence. Values can be seen in Table 62 with details of the evaluation below.

Table 62: Isotopic Water Composition - $\delta^{18}O$-(H_2O) Calibration Uncertainty Estimation 2014.

All Uncertainties given in ‰		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Water Standards	B	100	0.092
Repeatability	Calibration Repeatability	A	9	0.087
Reproducibilty	Calibration Reproducibility	A	8	0.066
Repeatability	Sensor Repeatability	A	3	0.082
Combined	Calibration Combined Uncertainty	eff	39	0.14
Expanded	Calibration Expanded Uncertainty	k	2.02	0.29

TRUTH: INSTARR provided analysis of the water standards created for NEON. The estimated uncertainty in the standards includes taking the maximum uncertainty from IAEA standards and maximum analytical uncertainty and combining them in quadrature.

CALIBRATION REPEATABILITY: The calibration utilizes a high, mid and low isotopic composition standards. For each standard, 3 points make up what is averaged for the fit. The difference between the water standard and the applied fit is used for this uncertainty. The maximum found for the 8 calibration was used.

CALIBRATION REPRODUCIBILITY: The reproducibility of 8 calibrations for one UUT was considered here. The water channel was not varied however. In future, each calibration will be both a water channel and isotopic calibration.

SENSOR REPEATABILITY: For each standard, 3 points make up what is averaged for the fit. The maximum standard deviation for these three points over eight calibrations was taken.

TRACEABILITY: All documents for the standards were located with details in Table 63. Table 64 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirements, NEON.CVAL.4.1049 may not be upheld.

Table 63: Document Traceability for the Isotopic Water Composition - $\delta^{18}O$-(H_2O) Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\IAEA	VSMOW2_SLAP2_2014.pdf	IAEA Refernece Sheet
N:\DEPT\CVL\Manufacturer Calibration Certificates\INSTARR	INSTARR Analysis of Secondary Water Standards.docx	INSTARR Analysis

Table 64: Requirements for the Isotopic Water Composition - $\delta^{18}O$-(H_2O) Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials
NEON.CVAL.3.1035	Isotope analyzers for d2H-(H2O), d18O-(H2O), d13C-(CO2) shall be calibrated prior to deployment and at a minimum annually using high accuracy working standards traceable to international standards organizations.
NEON.CVAL.3.1061	The system shall use standard materials provided by or traceable to reference materials that define each isotopic scale provided by the National Institute of Standards and Technology (NIST) and /or the International Atomic Energy Agency (IAEA).
NEON.CVAL.4.1027	The system shall adopt certified values and established isotope reference scales defined by the Commission on Isotopic Abundances and Atomic Weights (CIAAW) of International Union of Pure and Applied Chemistry (IUPAC).
NEON.CVAL.4.1028	The system shall follow isotopic scales for δH2-(H2O) and δO18-(H2O) established by the IAEA and the isotopic scale established for δC13-(CO2) established by the WMO.
NEON.CVAL.4.1029	The isotope analyzers shall be calibrated to the following criteria: ±1‰ for δH2-(H2O); ±0.2‰ for δO18-(H2O); and ±0.3‰ for δC13-(CO2).

25 ISOTOPIC WATER COMPOSITION - δ^2H-(H_2O) (L2130; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1W200

NEON PART #: 0328050000

CALIBRATION DESCRIPTION: The calibration of the L2130 includes a water channel calibration followed by the secondary standards traceable to IAEA being sent through the analyzer. Secondary standards have been analyzed by INSTARR for isotopic water composition and uncertainty. The analyzer takes 10 readings and the last 3 of those reading are used for the calibration fit. For more information on the calibration, see NEON.DOC.002422. The uncertainty evaluation resulted in Y = y ± 2.4 ‰ with 95% level of confidence. Values can be seen in Table 65 with details of the evaluation below.

Table 65: Isotopic Water Composition - δ^2H-(H_2O) Calibration Uncertainty Estimation 2014.

All Uncertainties given in ‰		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Water Standards	B	100	0.50
Repeatability	Calibration Repeatability	A	9	0.97
Reproducibilty	Calibration Reproducibility	A	8	0.36
Repeatability	Sensor Repeatability	A	3	0.50
Combined	Calibration Combined Uncertainty	eff	15	1.15
Expanded	Calibration Expanded Uncertainty	k	2.13	2.4

TRUTH: INSTARR provided analysis of the water standards created for NEON. The estimated uncertainty in the standards includes taking the maximum uncertainty from IAEA standards and maximum analytical uncertainty and combining them in quadrature.

CALIBRATION REPEATABILITY: The calibration utilizes a high, mid and low isotopic composition standards. For each standard, 3 points make up what is averaged for the fit. The difference between the water standard and the applied fit is used for this uncertainty. The maximum found for the 8 calibration was used.

CALIBRATION REPRODUCIBILITY: The reproducibility of 8 calibrations for one UUT was considered here. The water channel was not varied however. In future, each calibration will be both a water channel and isotopic calibration.

SENSOR REPEATABILITY: For each standard, 3 points make up what is averaged for the fit. The maximum standard deviation for these three points over eight calibrations was taken.

TRACEABILITY: All documents for the standards were located with details in Table 66. Table 67 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirements, NEON.CVAL.4.1049 may not be upheld.

Table 66: Document Traceability for the Isotopic Water Composition - δ^2H-(H_2O) Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\IAEA	VSMOW2_SLAP2_2014.pdf	IAEA Refernece Sheet
N:\DEPT\CVL\Manufacturer Calibration Certificates\INSTARR	INSTARR Analysis of Secondary Water Standards.docx	INSTARR Analysis

Table 67: Requirements for the Isotopic Water Composition - δ^2H-(H_2O) Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials
NEON.CVAL.3.1035	Isotope analyzers for d2H-(H2O), d18O-(H2O), d13C-(CO2) shall be calibrated prior to deployment and at a minimum annually using high accuracy working standards traceable to international standards organizations.
NEON.CVAL.3.1061	The system shall use standard materials provided by or traceable to reference materials that define each isotopic scale provided by the National Institute of Standards and Technology (NIST) and /or the International Atomic Energy Agency (IAEA).
NEON.CVAL.4.1027	The system shall adopt certified values and established isotope reference scales defined by the Commission on Isotopic Abundances and Atomic Weights (CIAAW) of International Union of Pure and Applied Chemistry (IUPAC).
NEON.CVAL.4.1028	The system shall follow isotopic scales for δH2-(H2O) and δO18-(H2O) established by the IAEA and the isotopic scale established for δC13-(CO2) established by the WMO.
NEON.CVAL.4.1029	The isotope analyzers shall be calibrated to the following criteria: ±1‰ for δH2-(H2O); ±0.2‰ for δO18-(H2O); and ±0.3‰ for δC13-(CO2).

26 ISOTOPIC WATER COMPOSITION – WATER CHANNEL (L2130; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1W600

NEON PART #: 0328050000

CALIBRATION DESCRIPTION: The calibration of the L2130 includes a water channel calibration followed by the secondary standards traceable to IAEA being sent through the analyzer. Secondary standards have been analyzed by INSTARR for isotopic water composition and uncertainty. The analyzer takes 10 readings and the last 3 of those reading are used for the calibration fit. For more information on the calibration, see NEON.DOC.002422. The uncertainty evaluation resulted in Y = y ± with 95% level of confidence. Values can be seen in Table 68 with details of the evaluation below.

Table 68: Isotopic Water Composition – Water Channel Calibration Uncertainty Estimation 2014.

TRUTH:

CALIBRATION REPEATABILITY:

CALIBRATION REPRODUCIBILITY:

SENSOR REPEATABILITY:

TRACEABILITY: All documents for the standards were located with details in Table 69. Table 70 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirements, NEON.CVAL.4.1049 may not be upheld.

Table 69: Document Traceability for the Isotopic Water Composition – Water Channel Calibration.

Table 70: Requirements for the Isotopic Water Composition – Water Channel Calibration.

27 MULTISONDE - CONDUCTIVITY (EXO; YSI; YELLOW SPRINGS, OH)

FIXTURE #: L1F200

NEON PART #: 0320170001

CALIBRATION DESCRIPTION: The Sonde is calibrated by submerging the sensors in standard solution. The Sonde does internal calculations for development of calibration coefficients and QAQC; therefore, CVAL has little control over the calibration. For more information on the calibration, see NEON.DOC.001215. The uncertainty evaluation resulted in Y = y ± 1.16% with 95% level of confidence. Values can be seen in Table 71 with details of the evaluation below.

Table 71: MultiSonde - Conductivity Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of reading		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Solution	B	100	0.58%
Repeatability	Calibration Repeatability	A	50	0.028%
Reproducibilty	Calibraiton Reproducibility	A	10	0.088%
Repeatability	Sensor Repeatability	A	50	0.0141%
Combined	Calibration Combined Uncertainty	eff	104	0.585%
Expanded	Calibration Expanded Uncertainty	k	1.98	1.16%

CAVEAT: Uncertainty was only assessed at 1000 µS.

TRUTH: YSI: 3167 1000 µS conductivity solution is traceable to NIST with 1%. Because it is not specified if this is an accuracy or tolerance, tolerance is assumed for worst case.

CALIBRATION REPEATABILITY: Six sensors were evaluated over 10 calibrations and the worst case t calibration repeatability made up of 50 data points was used. The calibration repeatability was the difference between the calibrated UUT and the solution.

CALIBRATION REPRODUCIBILITY: Six sensors were evaluated over 10 calibrations. The worst case standard deviation over those 10 calibrations for six sensors was used.

SENSOR REPEATABILITY: The calibration takes 50 readings to develop the calibration, the repeatability of 50 readings was calculated for the 6 six sensors and 10 calibrations and the worst case was used.

TRACEABILITY: All YSI traceability of their solutions can be found at http://www.ysi.com/accessories. Table 72 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 72: Requirements for the MultiSonde - Conductivity Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials
NEON.CVAL.4.1043	The electrical conductance sensors shall be calibrated to within the following tolerances: ±5 percent for conductivity ≤100 µsiemens/cm; and ±3 percent for conductivity >100 µsiemens/cm.

28 MULTISONDE -pH (EXO; YSI; YELLOW SPRINGS, OH)

FIXTURE #: L1F300

NEON PART #: 0320170015

CALIBRATION DESCRIPTION: The Sonde is calibrated by submerging the sensors in standard solution. The Sonde does internal calculations for development of calibration coefficients and QAQC; therefore, CVAL has little control over the calibration. For more information on the calibration, see NEON.DOC.001215. The uncertainty evaluation resulted in Y = y ± 4.99% with 95% level of confidence. Values can be seen in Table 73 with details of the evaluation below.

Table 73: MultiSonde - pH Calibration Uncertainty Estimation 2014.

All Uncertainties given in pH		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Solution	B	100	0.0058
Repeatability	Calibration Repeatability	A	50	0.00
Reproducibilty	Calibraiton Reproducibility	A		
Repeatability	Sensor Repeatability	A	50	0.00
Combined	Calibration Combined Uncertainty	eff	99	0.0058
Expanded	Calibration Expanded Uncertainty	k	1.98	0.011

CAVEAT: Uncertainty was only assessed at pH 4, 7, and 10.

TRUTH: YSI: 3822, 3821, 3823 pH solutions are traceable to NIST with ±0.01 pH units. Because it is not specified if this is an accuracy or tolerance, tolerance is assumed for worst case.

CALIBRATION REPEATABILITY: Five sensors were evaluated over 5 calibrations and the worst case calibration repeatability made up of 50 data points was used. The calibration repeatability was the difference between the calibrated UUT and the solution.

CALIBRATION REPRODUCIBILITY: Presently, reproducibility cannot be assessed due to the manufacturer not providing algorithm access for application of the coefficients. I am presently working with them on previous data available that could represent this metric.

SENSOR REPEATABILITY: The calibration takes 50 readings to develop the calibration, the repeatability of 50 readings was calculated for the 5 sensors and 5 calibrations and the worst case was used.

TRACEABILITY: All YSI traceability of their solutions can be found at http://www.ysi.com/accessories. Table 74 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 74: Requirements for the MultiSonde - pH Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials
NEON.CVAL.3.1046	pH sensors shall be calibrated prior to deployment and at a minimum annually using buffer solutions that are traceable to a NIST standard reference material (e.g. SRMs 186g and 191c) according to procedures recommended by the USGS Techniques for Water Resources Investigations Field Manual.
NEON.CVAL.4.1044	The calibrated pH sensors shall be calibrated to within 0.2 pH units of the appropriate standards.

29 MULTISONDE -Chlorophyll (EXO; YSI; YELLOW SPRINGS, OH)

FIXTURE #: L1F400

NEON PART #: 0320170005

CALIBRATION DESCRIPTION: The Sonde is calibrated by submerging the sensors in standard solution. The Sonde does internal calculations for development of calibration coefficients and QAQC; therefore, CVAL has little control over the calibration. The standard solution for chlorophyll is developed in house through a serious of dilutions of liquid red dye from Cole Palmer. This is currently not a traceable calibration. For more information on the calibration, see NEON.DOC.001215. The uncertainty evaluation resulted in Y = y ± 4.70% with 95% level of confidence. Values can be seen in Table 75 with details of the evaluation below. Do note that the uncertainty in the solution used for the truth is unquantifiable. Please see "TRUTH" description below.

Table 75: MultiSonde - Chlorophyll Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of reading		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	unquatifiable			
Repeatability	Calibration Repeatability	A	50	0.135%
Reproducibilty	Calibraiton Reproducibility	A	10	2.072%
Repeatability	Sensor Repeatability	A	50	0.0724%
Combined	Calibration Combined Uncertainty	eff	9	2.08%
Expanded	Calibration Expanded Uncertainty	k	2.26	4.70%

CAVEAT: Uncertainty was only assessed at 65 µg/L.

TRUTH: This calibration is not traceable due to there not being a standard dye solution. In future, this could be analyzed by the Horiba, but the manufacturer does not quote accuracy for this sensor because of this fact.

CALIBRATION REPEATABILITY: Five sensors were evaluated over 10 calibrations and the worst case calibration repeatability made up of 50 data points was used. The calibration repeatability was the difference between the calibrated UUT and the solution.

REPRODUCIBILITY: Five sensors were evaluated over 10 calibrations. The worst case standard deviation over those 10 calibrations for six sensors was used.

SENSOR REPEATABILITY: The calibration takes 50 readings to develop the calibration, the repeatability of 50 readings was calculated for the five sensors and 10 calibrations and the worst case was used.

TRACEABILITY: This calibration is not traceable. Table 76 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 76: Requirements for the MultiSonde - Chlorophyll Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials

30 MULTISONDE - TURBIDITY (EXO; YSI; YELLOW SPRINGS, OH)

FIXTURE #: L1F500

NEON PART #: 0320170004

CALIBRATION DESCRIPTION: The Sonde is calibrated by submerging the sensors in standard solution. The Sonde does internal calculations for development of calibration coefficients and QAQC; therefore, CVAL has little control over the calibration. For more information on the calibration, see NEON.DOC.001215. The uncertainty evaluation resulted in Y = y ± 1.56% with 95% level of confidence. Values can be seen in Table 77 with details of the evaluation below.

Table 77: MultiSonde - Turbidity Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of reading		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Solution	B	100	0.577%
Repeatability	Calibration Repeatability	A	50	0.116%
Reproducibilty	Calibraiton Reproducibility	A	10	0.501%
Repeatability	Sensor Repeatability	A	50	0.0862%
Combined	Calibration Combined Uncertainty	eff	44	0.77%
Expanded	Calibration Expanded Uncertainty	k	2.02	1.56%

CAVEAT: Uncertainty was only assessed at 124 NTU.

TRUTH: YSI: 6073G solution is traceable to NIST with ±0.01%. Because it is not specified if this is an accuracy or tolerance, tolerance is assumed for worst case.

CALIBRATION REPEATABILITY: Five sensors were evaluated over 10 calibrations and the worst case calibration repeatability made up of 50 data points was used. The calibration repeatability was the difference between the calibrated UUT and the solution.

CALIBRATION REPRODUCIBILITY: Five sensors were evaluated over 10 calibrations. The worst case standard deviation over those 10 calibrations for six sensors was used.

SENSOR REPEATABILITY: The calibration takes 50 readings to develop the calibration, the repeatability of 50 readings was calculated for the five sensors and 10 calibrations and the worst case was used.

TRACEABILITY: All YSI traceability of their solutions can be found at http://www.ysi.com/accessories. Table 78 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 78: Requirements for the MultiSonde - Turbidity Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials
NEON.CVAL.3.1047	Turbidity sensors shall be calibrated prior to deployment and at a minimum annually using turbidity standards that comply with EPA method 180.1 according to procedures recommended by the USGS Techniques for Water Resources Investigations Field Manual.
NEON.CVAL.4.1045	The calibrated turbidity sensors shall be calibrated to within ±5 percent over the range of expected field values.

31 MULTISONDE - fDOM (EXO; YSI; YELLOW SPRINGS, OH)

FIXTURE #: L1F600

NEON PART #: 0320170006

CALIBRATION DESCRIPTION: The Sonde is calibrated by submerging the sensors in standard solution. The Sonde does internal calculations for development of calibration coefficients and QAQC; therefore, CVAL has little control over the calibration. The standard solution for fDom (quinine sulfate) is created in house with sulfuric acid and quinine sulfate powder. This is currently not a traceable calibration. For more information on the calibration, see NEON.DOC.001215. The uncertainty evaluation resulted in Y = y ± 0.674% with 95% level of confidence. Values can be seen in Table 79 with details of the evaluation below. Do note that the uncertainty in the solution used for the truth is unquantifiable. Please see "TRUTH" description below.

Table 79: MultiSonde –fDOM Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of reading		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Unquantifiable			
Repeatability	Calibration Repeatability	A	50	0.126%
Reproducibilty	Calibraiton Reproducibility	A	10	0.283%
Repeatability	Sensor Repeatability	A	50	0.00313%
Combined	Calibration Combined Uncertainty	eff	13	0.310%
Expanded	Calibration Expanded Uncertainty	k	2.18	0.674%

TRUTH: This calibration is not traceable due to there not being a standard 300 ppm quinine sulfate solution. In future, this could be analyzed by the Horiba, but the manufacturer does not quote accuracy for this sensor because of this fact.

CALIBRATION REPEATABILITY: Five sensors were evaluated over 10 calibrations and the worst case repeatability made up of 50 data points was used. The repeatability was the difference between the calibrated UUT and the solution.

CALIBRAITON REPRODUCIBILITY: Five sensors were evaluated over 10 calibrations. The worst case standard deviation over those 10 calibrations for six sensors was used.

SENSOR REPEATABILITY : The calibration takes 50 readings to develop the calibration, the repeatability of 50 readings was calculated for the five sensors and 10 calibrations and the worst case was used.

TRACEABILITY: This calibration is currently not traceable. Table 80 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld.

Table 80: Requirements for the MultiSonde –fDOM Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1053	At calibration and validation laboratories, accuracy shall be traceable to standard reference materials

32 SOIL CO_2 (GMP343; VAISALLA; LOUISVILLE, CO)

FIXTURE #: L1G300

NEON PART #: 0300240000

CALIBRATION DESCRIPTION: Presently, the calibration utilizes CO2 in air gas standards for the truth in this calibration. The gas is sent through a sealed system maintaining a positive pressure of ~2 psig. The gases used include 500, 1,000, 2,000, 5,000, 10,000, 15,000, and 20,000 ppm. These gases are going to change to capture a better ambient range; therefore, this uncertainty is a quick estimation for the calibration as it exists for any sensors that could be needed on demand. Once the new calibration gases arrive, this evaluation will be repeated for more sensors. The pressure and temperature are captured during the calibration. Temperature is validated in the sensor and pressure and body temperature are used to calculate temperature, pressure, oxygen and relative humidity compensated concentrations from the raw concentration. For more information on the calibration, see NEON.DOC.001214. The uncertainty evaluation resulted in Y = y ± 2.74% with 95% level of confidence. Values can be seen in Table 81 with details of the evaluation below.

Table 81: Soil CO_2 Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of reading		**Type of Assessment**	**n/Deg of Freedom**	**Uncertainty**
Truth	Gas Standards	B	100	0.333%
Repeatability	Calibration Repeatability	A	20	1.08%
Reproducibility	Calibration Reproducibility	A	13	0.740%
Repeatability	Sensor Repeatability	A	20	0.600%
Combined	Calibration Combined Uncertainty	eff	34	1.35%
Expanded	Calibration Expanded Uncertainty	k	2.03	2.74%

TRUTH: The reference class gas standards from Air Liquide used for this calibration are quoted at 1% accuracy, so dividing these by 3, the uncertainty is ~0.33%.

CALIBRATION REPEATABILITY: The difference between the gas standard value and the UUT reading with coefficients applied provides the calibration repeatability. One sensor was evaluated for this estimation due to additional modifications coming down the pipeline.

CALIBRAITON REPRODUCIBILITY: The calibration was reproduced 13 times for one sensor.

SENSOR REPEATABILITY: The calibration utilizes 20 readings at each gas standard. The maximum standard deviation for all set points through the 13 calibrations was used.

TRACEABILITY: All documents for the standards were located with details in Table 82. Table 83 provides an outline of the relevant requirements as they apply to the calibration. Presently NEON.CVAL.4.1023 may not be met due to calibration gases; however, it is predicted that this uncertainty will improve once the new gas selection in implemented. Additionally, NEON.CVAL.3.1032 is not me with the 1% gas standards, but this is the highest class that Air Liquide provides for CO2 in air.

Table 82: Document Traceability for the Soil CO_2 Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 5000ppm 1% SN CC161624 2013.pdf	5,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 1000ppm 1% SN CC180145 2013.pdf	10,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 2.01%ppm 1% SN ALM030984.pdf	2,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 1.50%ppm 1% SN CC250484 2013.pdf	15,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 1000ppm 1% SN AAL17927_2013.pdf	1,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 2.00%ppm 1% SN CC262459 2013.pdf	20,000 ppm CO2 in air
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	Air Liquide CO2 500ppm 1% SN AAL21536 2013.pdf	500 ppm CO2 in air
\\neon.local\cvl\CalibrationData\L1T2000000	21000000050952_WO2219_26657.xml	PRT Cal File
\\neon.local\cvl\CalibrationData\L1T2000000	21000000050953_WO2220_26658.xml	PRT Cal File
N:\DEPT\CVL\Manufacturer Calibration Certificates\Omega\PT-104A	Omega_PT104A_Temp Data logger SN AR887_038.pdf	PT-104A Cal Cert

Table 83: Requirements for the Soil CO_2 Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.4.1023	Passive sensors for soil CO2 shall be calibrated to within ± 5 mmol CO2 mol^-1 + 2% of reading over the range of 0 to 3000 mmol CO2 mol^-1 or to within ± 1.5% of range + 2% of reading for higher mixing ratios of CO2.
NEON.CVAL.4.1022	During calibration of passive sensors for soil CO2, temperature shall be controlled to within ±0.1 °C and pressure shall be measured to ±0.5 kPa.
NEON.CVAL.3.1032	Passive sensors for soil CO2 shall be calibrated prior to deployment and at a minimum annually using working standards (±0.5% accuracy) that span the range of CO2 concentrations encountered in the soil.

33 PM_{10} PARTICULATE SAMPLER (HIVOL 3000; ECOTECH; KNOXFIELD, VIC, AUSTRALIA)

FIXTURE #: L1J200

NEON PART #:

CALIBRATION DESCRIPTION: For more information on the calibration, see NEON.DOC.002367. The uncertainty evaluation resulted in Y = y ± with 95% level of confidence. Values can be seen in Table 84 with details of the evaluation below.

Table 84: PM_{10} HiVol Calibration Uncertainty Estimation 2014.

TRUTH:

CALIBRATION REPEATABILITY:

CALIBRAITON REPRODUCIBILITY:

SENSOR REPEATABILITY:

TRACEABILITY: All documents for the standards were located with details in Table 85. Table 86 provides an outline of the relevant requirements as they apply to the calibration.

Table 85: Document Traceability for the PM_{10} HiVol Calibration.

Table 86: Requirements for the PM_{10} HiVol Calibration.

34 ORIFICE PLATE (HVS3000; ECOTECH; KNOXFIELD, VIC, AUSTRALIA)

FIXTURE #: L1J300

NEON PART #:

CALIBRATION DESCRIPTION: For more information on the calibration, see NEON.DOC.002543. The uncertainty evaluation resulted in Y = y ± with 95% level of confidence. Values can be seen in Table 87 with details of the evaluation below.

Table 87: Orifice Plate Calibration Uncertainty Estimation 2014.

TRUTH:

CALIBRATION REPEATABILITY:

CALIBRAITON REPRODUCIBILITY:

SENSOR REPEATABILITY:

TRACEABILITY: All documents for the standards were located with details in Table 88. Table 89 provides an outline of the relevant requirements as they apply to the calibration.

Table 88: Document Traceability for the Orifice Plate Calibration.

Table 89: Requirements for the Orifice Plate Calibration.

35 CARBON ISOTOPES – $\delta^{13}C$ (G2131; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1G500

NEON PART #: 0330600000

CALIBRATION DESCRIPTION: The calibration for the Picarro involves a characterization of the water channel using a optical hygrometer. Following this procedure, 3 calibration gases assayed by NOAA and INSTARR for CO_2-in-air concentration and isotopic carbon composition, respectively are used to calibrate the Picarro. The gases represent a low, medium, and high concentration and the gases are ramped up and then down. 300 stable readings at each gas concentration are taken for both the ramp up and ramp down portion and averaged for the calibration fit. For more information on the calibration, see NEON.DOC.002421. The uncertainty evaluation resulted in Y = y ± 0.31 ‰ with 95% confidence level. Values can be seen in Table 90 with details of the evaluation below.

Table 90: Carbon isotopes – $\delta^{13}C$ Calibration Uncertainty Estimation 2014.

All Uncertainties given in ‰		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	NOAA/INSTARR WMO traceable gases	B	14	0.02
Repeatability	Calibration Repeatability	A	604	0.089
Reproducibilty	Calibration Reproducibility	A	10	0.12
Repeatability	Sensor Repeatability	A	604	0.829
Combined	Calibration Combined Uncertainty	eff	23	0.15
Expanded	Calibration Expanded Uncertainty	k	2.07	0.31

TRUTH: The $\delta^{13}C$ values for the calibration gas standards are provided by INSTARR. INSTARR provides information about the calibration process that uncertainty could be derived for the assay procedure.

CALIBRATION REPEATABILITY: Repeatability was evaluated for 10 calibrations of 1 Picarro. Each set point (low, medium, and high) provided different trueness results for the 600 readings. The maximum for the 30 different repeatability results was used.

CALIBRATION REPRODUCIBILITY: The reproducibility was evaluated for 10 calibrations of 1 Picarro. Note that this did not utilize different water channel calibrations and was just a characterization with the gases. In future, the water channel will be varied.

SENSOR REPEATABILITY: Each set point has 600 readings. The repeatability was taken for each gas during the 10 calibrations. The maximum of these 30 different repeatability values was taken.

TRACEABILITY: All documents for the standards were located with details in Table 91. Table 92 provides an outline of the relevant requirements as they apply to the calibration. Depending on the interpretation of the requirement for accuracy, the values may just be over the ±0.3‰ in NEON.CVAL.4.1029, but this will likely improve with the recharacterization of the water channel for the reproducibility estimation.

Table 91: Document Traceability for the Carbon isotopes – δ^{13}C Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration

Table 92: Requirements for the Carbon isotopes – δ^{13}C Calibration.

NEON.CVAL.3.1035	Isotope analyzers for d2H-(H2O), d18O-(H2O), d13C-(CO2) shall be calibrated prior to deployment and at a minimum annually using high accuracy working standards traceable to international standards organizations.
NEON.CVAL.3.1061	The system shall use standard materials provided by or traceable to reference materials that define each isotopic scale provided by the National Institute of Standards and Technology (NIST) and /or the International Atomic Energy Agency (IAEA).
NEON.CVAL.4.1027	The system shall adopt certified values and established isotope reference scales defined by the Commission on Isotopic Abundances and Atomic Weights (CIAAW) of International Union of Pure and Applied Chemistry (IUPAC).
NEON.CVAL.4.1028	The system shall follow isotopic scales for δH2-(H2O) and δO18-(H2O) established by the IAEA and the isotopic scale established for δC13-(CO2) established by the WMO.
NEON.CVAL.4.1029	The isotope analyzers shall be calibrated to the following criteria: ±1‰ for δH2-(H2O); ±0.2‰ for δO18-(H2O); and ±0.3‰ for δC13-(CO2).

36 CARBON ISOTOPES – [^{12}C] (G2131; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1G500

NEON PART #: 0330600000

CALIBRATION DESCRIPTION: The calibration for the Picarro involves a characterization of the water channel using a optical hygrometer. Following this procedure, 3 calibration gases assayed by NOAA and INSTARR for CO_2-in-air concentration and isotopic carbon composition, respectively are used to calibrate the Picarro. The gases represent a low, medium, and high concentration and the gases are ramped up and then down. 300 stable readings at each gas concentration are taken for both the ramp up and ramp down portion and averaged for the calibration fit. For more information on the calibration, see NEON.DOC.002421. The uncertainty evaluation resulted in Y = y ± 0.0543% with 95% confidence level. Values can be seen in Table 93 with details of the evaluation below.

Table 93: Carbon Isotopes – [$^{12}CO_2$] Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	NOAA/INSTARR WMO traceable gases	B	201	0.0263%
Repeatability	Calibration Repeatability	A	604	0.00687%
Reproducibilty	Calibration Reproducibility	A	10	0.00464%
Repeatability	Sensor Repeatability	A	604	0.0363%
Combined	Calibration Combined Uncertainty	eff	236	0.0275%
Expanded	Calibration Expanded Uncertainty	k	1.97	0.0543%

TRUTH: The δ^{13}C from INSTARR combined with the CO_2-in-air concentrations from NOAA certification provides the necessary information for calculating the concentration of $^{12}CO_2$. Uncertainties were estimated by utilizing the uncertainties from those two assays and the below calculations:

$$R = \frac{[13\mathrm{CO}_2]}{[12\mathrm{CO}_2]} \tag{13}$$

$$[13\mathrm{CO}_2] = [12\mathrm{CO}_2] * R \tag{14}$$

$$\delta 13C = \left[\frac{\frac{[13\mathrm{CO}_2]}{[12\mathrm{CO}_2]}}{\frac{[13\mathrm{CO}_2]_s}{[12\mathrm{CO}_2]_s}} - 1 \right] * 1000 \tag{15}$$

$$[\mathrm{CO_2}] = \frac{[12\mathrm{CO_2}] + [13\mathrm{CO_2}]}{(1 - f_{o\ he}\ )} = [12\mathrm{CO_2}] * \left[\frac{1 + \frac{[13\mathrm{CO_2}]}{[12\mathrm{CO_2}]}}{(1 - f_{o\ he}\ )}\right] = [12\mathrm{CO_2}] * \left[\frac{1 + R}{(1 - f_{o\ he}\ )}\right] \tag{16}$$

where $[\mathrm{CO_2}]$ is the average CO_2 concentration in the air, K_V is the Vienna Pee Dee Belemnite (VPDB) standard reference for the ratio of $\frac{[1\ \ C\ \ _2]_S}{[1\ \ C\ \ _2]_S}$ which is 0.0111802, and $f_{o\ he}$ is the fraction of CO2 containing all isotopologues other than $^{12}C^{16}O^{16}O$ and $^{13}C^{16}O^{16}O$ and assume to be 0.00474. Note that no uncertainty is added for the uncertainty in these equations.

CALIBRATION REPEATABILITY: Repeatability was evaluated for 10 calibrations of 1 Picarro. Each set point (low, medium, and high) provided different repeatability results for the 600 readings. The maximum for the 30 different trueness results was used.

REPRODUCIBILITY: The reproducibility was evaluated for 10 calibrations of 1 Picarro. Note that this did not utilize different water channel calibrations and was just a characterization with the gases. In future, the water channel will be varied.

SENSOR REPEATABILITY: Each set point has 600 readings. The repeatability was taken for each gas during the 10 calibrations. The maximum of these 30 different repeatability values was taken.

TRACEABILITY: All documents for the standards were located with details in Table 94. Table 95 provides an outline of the relevant requirements as they apply to the calibration.

Table 94: Document Traceability for the Carbon Isotopes – [^{12}C] Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration

Table 95: Requirements for the Carbon Isotopes – [^{12}C] Calibration.

NEON.CVAL.3.1035	Isotope analyzers for d2H-(H2O), d18O-(H2O), d13C-(CO2) shall be calibrated prior to deployment and at a minimum annually using high accuracy working standards traceable to international standards organizations.
NEON.CVAL.3.1061	The system shall use standard materials provided by or traceable to reference materials that define each isotopic scale provided by the National Institute of Standards and Technology (NIST) and /or the International Atomic Energy Agency (IAEA).
NEON.CVAL.4.1027	The system shall adopt certified values and established isotope reference scales defined by the Commission on Isotopic Abundances and Atomic Weights (CIAAW) of International Union of Pure and Applied Chemistry (IUPAC).
NEON.CVAL.4.1028	The system shall follow isotopic scales for δH2-(H2O) and δO18-(H2O) established by the IAEA and the isotopic scale established for δC13-(CO2) established by the WMO.
NEON.CVAL.4.1029	The isotope analyzers shall be calibrated to the following criteria: ±1‰ for δH2-(H2O); ±0.2‰ for δO18-(H2O); and ±0.3‰ for δC13-(CO2).

37 CARBON ISOTOPES – [^{13}C] (G2131; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1G500

NEON PART #: 0330600000

CALIBRATION DESCRIPTION: The calibration for the Picarro involves a characterization of the water channel using a optical hygrometer. Following this procedure, 3 calibration gases assayed by NOAA and INSTARR for CO_2-in-air concentration and isotopic carbon composition, respectively are used to calibrate the Picarro. The gases represent a low, medium, and high concentration and the gases are ramped up and then down. 300 stable readings at each gas concentration are taken for both the ramp up and ramp down portion and averaged for the calibration fit. For more information on the calibration, see NEON.DOC.002421. The uncertainty evaluation resulted in Y = y ± % with 95% confidence level. Values can be seen in Table 96 with details of the evaluation below.

Table 96: Carbon isotopes – [^{13}C] Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	NOAA/INSTARR WMO traceable gases	B	202	0.0263%
Repeatability	Calibration Repeatability	A	604	0.0325%
Reproducibilty	Calibration Reproducibility	A	10	0.0109%
Repeatability	Sensor Repeatability	A	604	0.0862%
Combined	Calibration Combined Uncertainty	eff	603	0.0432%
Expanded	Calibration Expanded Uncertainty	k	1.96	0.0849%

TRUTH: The δ^{13}C from INSTARR combined with the CO_2-in-air concentrations from NOAA certification provides the necessary information for calculating the concentration of $^{13}CO_2$. Uncertainties were estimated by utilizing the uncertainties from those two assays and the calculations in Section 35 and Equations 13 – 16.

CALIBRATION REPEATABILITY: Repeatability was evaluated for 10 calibrations of 1 Picarro. Each set point (low, medium, and high) provided different trueness results for the 600 readings. The maximum for the 30 different repeatability results was used.

CALIBRATION REPRODUCIBILITY: The reproducibility was evaluated for 10 calibrations of 1 Picarro. Note that this did not utilize different water channel calibrations and was just a characterization with the gases. In future, the water channel will be varied.

SENSOR REPEATABILITY: Each set point has 600 readings. The repeatability was taken for each gas during the 10 calibrations. The maximum of these 30 different repeatability values was taken.

TRACEABILITY: All documents for the standards were located with details in Table 97. Table 98 provides an outline of the relevant requirements as they apply to the calibration.

Table 97: Document Traceability for the Carbon isotopes – ^{13}C Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887co2.pdf	NOAA Certification of Calibration CO_2-in-air
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09640silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09853silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration
N:\DEPT\CVL\Manufacturer Calibration Certificates\NOAA WMO Primary Standard Compressed Gas Cylinders	CB09887silco2.doc	INSTARR Certificate of Isotopic CO_2 Calibration

Table 98: Requirements for the Carbon isotopes – ^{13}C Calibration.

NEON.CVAL.3.1035	Isotope analyzers for d2H-(H2O), d18O-(H2O), d13C-(CO2) shall be calibrated prior to deployment and at a minimum annually using high accuracy working standards traceable to international standards organizations.
NEON.CVAL.3.1061	The system shall use standard materials provided by or traceable to reference materials that define each isotopic scale provided by the National Institute of Standards and Technology (NIST) and /or the International Atomic Energy Agency (IAEA).
NEON.CVAL.4.1027	The system shall adopt certified values and established isotope reference scales defined by the Commission on Isotopic Abundances and Atomic Weights (CIAAW) of International Union of Pure and Applied Chemistry (IUPAC).
NEON.CVAL.4.1028	The system shall follow isotopic scales for δH2-(H2O) and δO18-(H2O) established by the IAEA and the isotopic scale established for δC13-(CO2) established by the WMO.
NEON.CVAL.4.1029	The isotope analyzers shall be calibrated to the following criteria: ±1‰ for δH2-(H2O); ±0.2‰ for δO18-(H2O); and ±0.3‰ for δC13-(CO2).

38 CARBON ISOTOPES – CO_2 CONCENTRATION (G2131; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1G500

NEON PART #: 0330600000

CALIBRATION DESCRIPTION: The calibration for the Picarro involves a characterization of the water channel using a optical hygrometer. Following this procedure, 3 calibration gases assayed by NOAA and INSTARR for CO_2-in-air concentration and isotopic carbon composition, respectively are used to calibrate the Picarro. The gases represent a low, medium, and high concentration and the gases are ramped up and then down. 300 stable readings at each gas concentration are taken for both the ramp up and ramp down portion and averaged for the calibration fit. For more information on the calibration, see NEON.DOC.002421. The uncertainty evaluation resulted in Y = y ± 0.22 ppm with 95% confidence level. Values can be seen in Table 99 with details of the evaluation below.

Table 99: Carbon isotopes – CO_2 Concentration Calibration Uncertainty Estimation 2014.

All Uncertainties given in ppm		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	NOAA/INSTARR WMO traceable gases	B	78	0.11
Repeatability	Calibration Repeatability	A	604	0.029
Reproducibilty	Calibration Reproducibility	A	10	0.022
Repeatability	Sensor Repeatability	A	604	0.1800
Combined	Calibration Combined Uncertainty	eff	95	0.11
Expanded	Calibration Expanded Uncertainty	k	1.99	0.22

TRUTH: The $\delta^{13}C$ from INSTARR combined with the CO_2-in-air concentrations from NOAA certification provides the necessary information for calculating the concentration of $^{13}CO_2$. Uncertainties were estimated by utilizing the uncertainties from those two assays and the calculations in Section 35 and Equations 13 – 16.

CALIBRATION REPEATABILITY: Repeatability was evaluated for 10 calibrations of 1 Picarro. Each set point (low, medium, and high) provided different trueness results for the 600 readings. The maximum for the 30 different repeatability results was used.

CALIBRATION REPRODUCIBILITY: The reproducibility was evaluated for 10 calibrations of 1 Picarro. Note that this did not utilize different water channel calibrations and was just a characterization with the gases. In future, the water channel will be varied.

SENSOR REPEATABILITY: Each set point has 600 readings. The repeatability was taken for each gas during the 10 calibrations. The maximum of these 30 different repeatability values was taken.

TRACEABILITY: All documents for the standards were located with details in Table 100. Table 101 provides an outline of the relevant requirements as they apply to the calibration.

Table 100: Document Traceability for the Carbon isotopes – CO_2 Concentration Calibration.

Table 101: Requirements for the Carbon isotopes – CO_2 Concentration Calibration.

39 CARBON ISOTOPES – WATER CHANNEL CALIBRATION (G2131; PICARRO; SANTA CLARA, CA)

FIXTURE #: L1W500

NEON PART #: 0330600000

CALIBRATION DESCRIPTION: The calibration for the Picarro involves a characterization of the water channel using a optical hygrometer. Following this procedure, 3 calibration gases assayed by NOAA and INSTARR for CO_2-in-air concentration and isotopic carbon composition, respectively are used to calibrate the Picarro. The gases represent a low, medium, and high concentration and the gases are ramped up and then down. 300 stable readings at each gas concentration are taken for both the ramp up and ramp down portion and averaged for the calibration fit. For more information on the calibration, see NEON.DOC.002421. The uncertainty evaluation resulted in Y = y ± with 95% confidence level. Values can be seen in Table 102 with details of the evaluation below.

Table 102: Carbon isotopes – Water Channel Calibration Uncertainty Estimation 2014.

TRUTH: The $\delta^{13}C$ from INSTARR combined with the CO_2-in-air concentrations from NOAA certification provides the necessary information for calculating the concentration of $^{13}CO_2$. Uncertainties were estimated by utilizing the uncertainties from those two assays and the calculations in Section 35 and Equations 13 – 16.

CALIBRATION REPEATABILITY: Repeatability was evaluated for 10 calibrations of 1 Picarro. Each set point (low, medium, and high) provided different trueness results for the 600 readings. The maximum for the 30 different repeatability results was used.

CALIBRATION REPRODUCIBILITY: The reproducibility was evaluated for 10 calibrations of 1 Picarro. Note that this did not utilize different water channel calibrations and was just a characterization with the gases. In future, the water channel will be varied.

SENSOR REPEATABILITY: Each set point has 600 readings. The repeatability was taken for each gas during the 10 calibrations. The maximum of these 30 different repeatability values was taken.

TRACEABILITY: All documents for the standards were located with details in Table 103. Table 104 provides an outline of the relevant requirements as they apply to the calibration.

Table 103: Document Traceability for the Carbon isotopes – Water Channel Calibration.

Table 104: Requirements for the Carbon isotopes – Water Channel Calibration.

40 IRGA - CARBON DIOXIDE CONCENTRATION (IRGA; LI-COR; LINCOLN, NE)

FIXTURE #: L1G200

NEON PART #: CA04430000

CALIBRATION DESCRIPTION: Zero air and 5 different concentrations of gases ranging from below to above ambient are used for the calibration. 3 temperatures of ~0, 20, and 30°C are maintained while these gases run through the fixture by ramping up and down through the concentrations with 36 set points in total (6x2x3). 300 readings are taken at each set point. For more information on the calibration, see NEON.DOC.002474. The uncertainty evaluation resulted in Y = y ± 3.67% with 95% level of confidence. Values can be seen in Table 105 with details of the evaluation below.

Table 105: IRGA – CO_2 Concentration Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of ppm reading		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	CO_2 Certified Cylinders*	B	100	0.667%
Repeatability	Calibration Repeatability	A	300	1.79%
Reproducibilty	Reproducibility	A	4	0.387%
Repeatability	Repeatability	A	300	0.088%
Combined	Uncertainty	eff	331	1.95%
Expanded	Uncertainty	k	1.97	3.84%

***TRUTH:** This analysis was done with cylinders that were expired; therefore, this analysis is not traceable. However, it is an estimate for the capability of the fixture. Additionally, one cylinder had an accuracy of 2%; therefore, this was used in the uncertainty estimation using Equation 10a. Under normal operating procedures, certified cylinders will have a more accurate and traceable certification.

CALIBRATION REPEATABILITY: At each set point, the 300 readings of the calibrated LI7200 carbon dioxide concentration (ppm) readings versus the certified value of the cylinders were compared using Equation 11 and divided by the cylinder concentration for each set point. The maximum for the calibration run was taken and then the maximum of the 4 reproduced runs were taken for the 3 units considered.

CALIBRAITON REPRODUCIBILITY: The calibration coefficients for the 4 reproduced runs were used to translate a single run of raw data into 4 unique results for a single reading. The standard deviation of the 4 results were taken and the maximum throughout the entire run was taken for the 3 units considered.

SENSOR REPEATABILITY: At each set point, the standard deviation of 300 carbon dioxide concentration (ppm) readings were taken and divided by the average for the set point. The maximum for the calibration run was taken and then the maximum of the 4 reproduced runs were taken for the 3 units considered.

TRACEABILITY: This analysis was performed with non-traceable gases because of expiration. All documents for the standards were located with details in Table 106. Table 107 provides an outline of the relevant requirements as they apply to the calibration.

Table 106: Document Traceability for the IRGA - CO_2 Concentration Calibration.

Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2\CO2 400ppm	Air Liquide CO2 400ppm SN EB0011208.pdf	Air Liquide Certified 2% 2011
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\Zero Air	Air Liquide Zero Air SN ALM044635_2014.pdf	Air Liquide Certified 2014
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	CO2 334 ppm SN ALM045268.pdf	NOAA Certified 0.03% 2012
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	CO2 382 ppm SN ALM062680.pdf	NOAA Certified 0.03% 2012
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	CO2 515 ppm SN ALM049494.pdf	NOAA Certified 0.03% 2012
N:\DEPT\CVL\Manufacturer Calibration Certificates\Air Liquide\CO2	CO2 361 ppm SN ALM052231.pdf	NOAA Certified 0.03% 2012

Table 107: Requirements for the IRGA – CO_2 Concentration Calibration.

NEON.CVAL.4.1015	To calibrate CO2 dry mole fraction with ≤1% uncertainty, the IRGA cell temperature and pressure shall be controlled to within ≤ ± 0.3 °C and ≤ ± 0.6 kPa, respectively.
NEON.CVAL.4.1016	For measurements of turbulent exchange the CO2 analyzers shall be calibrated to within an offset accuracy of better than ± 1.0 µmol CO2 mol^-1 with a linear response (gain) better than ± 5%.
NEON.CVAL.4.1059	The measurements of the turbulent fluctuations of H2O under steady state conditions shall be made consistently among all domains with an accuracy of ≤ ± 3% and a precision ≤ ±0.1 mmol H2O mol-1 over the range of expected values 0 - 60 mmol H20 mol-1 to known and traceable international standards.
NEON.CVAL.4.1060	The measurements of the turbulent fluctuations of CO2 under steady state conditions shall be made consistently among all domains with an accuracy of ≤ ±2% and a precision ≤ ±0.2 µmol CO2 mol-1 over the range of expected values 320 to 900 µmol CO2 mol-1 (to known and traceable international standards from 325 to 500 µmol CO2 mol-1).

41 IRGA - WATER CHANNEL CALIBRATION (IRGA; LI-COR; LINCOLN, NE)

FIXTURE #: L1G200

NEON PART #: CA04430000

CALIBRATION DESCRIPTION: The water channel characterization is performed with a NIST traceable Kahn Optical Hygrometer. The calibration is taken through 10 set point concentrations for water content with 100 readings taken at each set point. For more information on the calibration, see NEON.DOC.002474. This analysis considers 3 units, 1 operator, and 5 reproduced calibrations. The uncertainty evaluation resulted in Y = y ± 5.40% with 95% level of confidence. Values can be seen in Table 105 with details of the evaluation below.

Table 108: IRGA - Water Channel Calibration Uncertainty Estimation 2014.

All Uncertainties given in % of ppm_v reading		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Kahn	B	100	0.200%
Repeatability	Calibration Repeatability	A	100	2.53%
Reproducibility	Calibration Reproducibility	A	5	0.959%
Repeatability	Sensor Repeatability	A	100	0.449%
Combined	Calibration Combined Uncertainty	eff	87	2.71%
Expanded	Calibration Expanded Uncertainty	k	1.99	5.40%

TRUTH: The Kahn is calibrated at NIST for dew point. The total expanded uncertainty is estimated to be 0.05°C with a coverage factor assumed to be 2. A publication from NIST (Meyer et al., 2008) estimates a water content uncertainty of 0.2% for uncertainties of dew point temperature of 0.025°C. This is the approximation used for the truth uncertainty of the Kahn.

CALIBRATION REPEATABILITY: At each set point, the 100 readings of the Kahn and calibrated LI7200 water content (ppm_v) readings were calculated in the Equation 11 and divided by the average of the Kahn reading for each set point. The maximum for the calibration run was taken and then the maximum of the 5 reproduced runs were taken for the 3 units considered.

CALIBRAITON REPRODUCIBILITY: The calibration coefficients for the 5 reproduced runs were used to translate a single run of raw data into 5 unique results for a single reading. The standard deviation of the 5 results were taken and the maximum throughout the entire run was taken for the 3 units considered.

SENSOR REPEATABILITY: At each set point, the standard deviation of 100 water content (ppm_v) readings were taken and divided by the average for the set point. The maximum for the calibration run was taken and then the maximum of the 5 reproduced runs were taken for the 3 units considered.

TRACEABILITY: All documents for the standards were located with details in Table 106. Table 107 provides an outline of the relevant requirements as they apply to the calibration.

Table 109: Document Traceability for the IRGA - Water Channel Calibration.

Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Kahn	Kahn Optisure_Michell S8000 Integral SN 134674 NIST 2015.pdf	Kahn Calibration at NIST

Table 110: Requirements for the IRGA - Water Channel Calibration.

NEON.CVAL.4.1019	To calibrate H_2O mole fraction with ≤2% uncertainty, the IRGA cell temperature and pressure shall be controlled to within ≤ ± 0.6 °C and ≤ ± 0.6 kPa, respectively.
NEON.CVAL.4.1020	The H_2O vapor analyzers for eddy flux shall be calibrated to offset accuracy of better than ± 0.2 mmol mol^-1 and a linear response (gain) better than 5%.
NEON.CVAL.4.1059	The measurements of the turbulent fluctuations of H_2O under steady state conditions shall be made consistently among all domains with an accuracy of ≤ ± 3% and a precision ≤ ±0.1 mmol H_2O mol-1 over the range of expected values 0 - 60 mmol H20 mol-1 to known and traceable international standards.

42 PRIMARY PRECIPITATION (AEPG 600; BELFORT; BALTIMORE, MD)

FIXTURE #: L1P100

NEON PART #:

CALIBRATION DESCRIPTION: This calibration is performed with a collection of weights from 1 to 12 kg. The weight is then converted to cm of water based on assumptions of density and area. The weights are the truth in this case and the output of the sensor which is frequency is then correlated to the cm of water. For more information on the calibration, see NEON.DOC.001213. The uncertainty evaluation resulted in Y = y ± 1.46% with 95% level of confidence. Values can be seen in Table 111 with details of the evaluation below.

Table 111: Primary Precipitation Calibration Uncertainty Estimation 2014.

All Uncertainties given in %		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	Weight uncertainty	B	100	0.001%
Repeatability	Calibration Repeatability	B	100	0.734%
Reproducibilty	Calibration Reproducibility	A	12	0.074%
Repeatability	Sensor Repeatability	A	10	0.282%
Combined	Calibration Combined Uncertainty	eff	101	0.74%
Expanded	Calibration Expanded Uncertainty	k	1.98	1.46%

CAVEAT: The uncertainty was evaluated for 3 transducer output (i.e. an average of the 3 transducers). The current weight set being used is off center and causes an individual transducer to not be accurate independently. We are in the process of obtaining weight sets and configuring a set-up that will force a centralized weight and therefore allow individual transducers to be accurate. The current approximation for uncertainty should be repeatable for an individual transducer provided the weight is centralized. Once the new weight set comes in, the calibration will be re-evaluated.

TRUTH: Rice lake class 7 weight set are the truth in this case. The weights include 2X5 kg, 2X2 kg, and 1kg. The different combinations of weight were determined and the maximum possible uncertainty and offset from the weights were used in the calculation. The offset was added outside the quadrature because of the systematic nature.

CALIBRATION REPEATABILITY: The difference between the frequency conversion to water in cm vs. the given weight representation in depth of water is used for calibration repeatability. One sensor was evaluated for 12 calibrations and the worst case calibration repeatability for each weight combination was used.

CALIBRAITON REPRODUCIBILITY: One sensor was calibrated 12 times by two different operators. The reproducibility of the calibration coefficients was evaluated by standard deviation of the resulting depths.

SENSOR REPEATABILITY: 10 frequencies at each set point are averaged and therefore the maximum repeatability of the 12 test points for the 12 calibrations was used.

TRACEABILITY: All documents for the standards were located with details in Table 112. Table 113 provides an outline of the relevant requirements as they apply to the calibration. Depending on interpretation of the requirements, NEON.CVAL.4.1039 may not be upheld. However, the new weight set may improve the uncertainty.

Table 112: Document Traceability for the Primary Precipitation Calibration.

Current Location:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Rice Lake	Rice Lake, Class 7 Weight Set, SN 4F9A to 4F9G.pdf	Weight set cal certs

Table 113: Requirements for the Primary Precipitation Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1042	Precipitation gauges shall be calibrated prior to deployment and at least annually thereafter.
NEON.CVAL.4.1039	Accuracy of precipitation amount and rate for primary measurements shall be calibrated to ±0.25 mm total or ±0.005 mm/minute.

43 SOIL PRT (THERMOMETRICS CORP; NORTHRIDGE, CA)

FIXTURE #: L1T300

NEON PART #: CA04430000

CALIBRATION DESCRIPTION: For more information on the calibration, see NEON.DOC.000723. The uncertainty evaluation resulted in Y = y ± 0.19°C with 95% level of confidence. Values can be seen in Table 114 with details of the evaluation below.

Table 114: Soil PRT Calibration Uncertainty Estimation 2014.

All Uncertainties given in °C		Type of Assessment	n/Deg of Freedom	Uncertainty
Truth	SPRT Calibration	B	100	1.2E-04
Repeatability	Calibration Repeatability	A	60	9.3E-03
DAS	(2x) CVAL NI DMM ED4305 PXI-4071	B	100	1.4E-05
Mux Box	(2x) Testing with 115 ohm resistor	A	32.8	9.1E-05
Reproducibilty	Calibration Reproducibility	A	10	8.1E-02
Repeatability	Sensor Repeatability	A	20	5.9E-02
Combined	Calibration Combined Uncertainty	eff	9	0.082
Expanded	Calibration Expanded Uncertainty	k	2.26	0.19

CAVEAT: Soil PRTs are currently under investigation for corrosion seen during calibration due to the alcohol of the baths. This analysis is the PRTs submerged in liquid. While some sensors performed okay, others showed definite differences in final calibration events once corrosion had affected the signal (at least that is the hypothesis). The estimate above is based on the testing with the included data from the corrosion. Additional sensors are needed to perform analysis on non-corroded sensors.

TRUTH: The SPRT Calibration is performed in house and follows the NIST Special Publication by Strouse (2008). In this document, the uncertainties are detailed as related with the calibration with the fixed point cells. Because the calibration performed by CVAL emulates these procedures, Type B evaluation was used from this published knowledge. However, in future, a Type A evaluation may be justified.

CALIBRATION REPEATABILITY: Calibration data from 5 UUTs was used for the calibration repeatability determination. The 20 data points of the 3 temperatures (50, 0, and -30 °C) used for fitting the curve were used to calculate the difference between the standard and the UUT.

DAS: Uncertainty values from the document National Instruments_PXI-4071_Serial Number EFEBC2.pdf were used as a Type B evaluation from a calibration certificate. The PXI-4071 used in the PRT calibration goes through the same calibration as the one detailed in this document, so the uncertainties were considered the same. The associated resistance calibration point was the 1k Ohm for 4 wire resistance which is consistent with the fixture wiring set-up. The calibration coefficients for 31 sensors and the resistance range of 120 through 88 ohms which corresponds to 50 through -30°C were used to transform the uncertainty into °C using the partial derivative of the second order polynomial. Therefore the uncertainty follows Equation 12:

$$u(y\,°C) = [2 * C \qquad 2 * (R) + C \qquad 1] * u(D \quad ohm\ ) \tag{12}$$

where R is the resistance taken through 120 through 88, CVALA2 and CVALA1 are calibration coefficients for a given sensor and u(DAS ohms) is from the calibration certificate noted above. Because the SPRT and PRT are taken through the same DAS, the contributing uncertainty is multiplied by two when adding in quadrature.

MUX BOX: The calibration of PRTs is taken through a mux box; therefore the uncertainty associated with switching through the 16 ports was determined using a 115 precision ohm resistor by Vishay (115R4920-5102K). 20 readings were taken on each port to determine the repeatability per port and reproducibility across the 16 ports. Finally, the reading of the precision resistor was taken without the mux box in place (i.e. directly into the DMM) and this reading was considered the truth for the "calibration repeatability" calculation. These uncertainties were added in quadrature, and the effective degrees of freedom was used from these experiments. Because the SPRT and PRT are taken through the same DAS, the contributing uncertainty is multiplied by two when adding in quadrature.

CALIBRAITON REPRODUCIBILITY: 5 UUTs were calibrated 10 times. The resistance range of 120 to 88 ohms was used to evaluate the 5 PRTs resulting calibration coefficients. The standard deviation of the predicted temperatures for the 10 calibrations was used for this term.

SENSOR REPEATABILITY: The calibration uses 20 readings at each set point to determine the calibration fit, therefore, 20 readings were used for the repeatability testing. The same calibration data from the 5 UUTs utilized in the calibration repeatability assessment was used.

TRACEABILITY: All documents as they apply to operating YR2014 were located for the calibrations of SPRTs and PRTs and can be found in Table 2. Table 3 provides an outline of the relevant requirements as they apply to the calibration. The PRT calibration is in compliance with the requirements.

TRACEABILITY: All documents for the standards were located with details in Table 115. Table 116 provides an outline of the relevant requirements as they apply to the calibration and all are currently being upheld. Depending on the interpretation of accuracy NEON.CVAL.3.1012 may not be upheld. However, the higher values are a function of the corrosion. More stable results were seen when corrosion was not present.

Table 115: Document Traceability for the Soil PRT Calibration.

Traceability of the PRT Calibration:	File Name:	Description:
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5901D Triple Point of Water	Fluke Corporation_5901D-Q The Triple Point of Water Cell_Serial Number D-Q1114.pdf	Triple Point of Water
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5901D Triple Point of Water	Fluke Corporation_5901D-Q The Triple Point of Water Cell_Serial Number D-Q1069.pdf	Triple Point of Water
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury	Fluke Corporation_5900E Triple Point of Mercury Cell_Serial Number Hg-00028.pdf	Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury	Fluke Corporation_5900E Triple Point of Mercury Cell_Serial Number Hg-00036.pdf	Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5900E Triple Point of Mercury		Triple Point of Mercury
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5943 Melting Point of Gallium	Fluke Corporation_5943 Melting Point of Gallium Cell_Serial Number Ga-43149.pdf	Melting Point of Gallium
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\5943 Melting Point of Gallium	Fluke Corporation_5943 Melting Point of Gallium Cell_Serial Number Ga-43114.pdf	Melting Point of Gallium
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\9230 Calibration Furnace	Fluke Corporation_9230_Calibration Furnace_Serial Number B38119.pdf	Gallium Maintenance Cell
N:\DEPT\CVL\Manufacturer Calibration Certificates\Fluke\9230 Calibration Furnace	Fluke Corporation_9230 Gallium Cell Maintenance Apparatus_Serial Number B08088.pdf	Gallium Maintenance Cell
N:\DEPT\CVL\Manufacturer Calibration Certificates\National Instruments\PXI 4071	National Instruments_PXI-4071_Serial Number ED4305_2013.pdf	National Instrument 7Â½ DMM and 1000 V Digitizer
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001183_WO1001_17048.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001182_WO1000_17046.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000051571_WO1002_17044.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050167_WO196_17042.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050166_WO195_17047.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050165_WO194_17043.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	30000000001184_WO955_17045.xml	SPRT Calibration Files
\\neon.local\cvl\CalibrationData\XML_CVAL	21000000050156_WO193_17049.xml	SPRT Calibration Files
N:\DEPT\CVL\QAQC\PRT	SPRT_Summary_2014.xlsx	SPRT Calibration History File

Table 116: Requirements for the Soil PRT Calibration.

NEON.CVAL.3.1002	The SDPM segment shall provide the necessary information to the DAQ segment to ensure the ongoing calibration and validation of field equipment
NEON.CVAL.3.1003	The Calibration and Validation element (CAL/VAL) element shall ensure accurate transformation of Level 0 data to Level 1 data products by providing the necessary staff and functions to calibrate and/or validate sensors and other data collection techniques
NEON.CVAL.3.1004	The system shall provide a Calibration and Validation Laboratory (CVL) Management Plan to document the overall management and processes of the CVL during construction and operations.
NEON.CVAL.3.1005	All instruments and observer-processes shall be calibrated against a set of recognized physical and biological standards and whenever possible, standards should be traceable to national and international standards.
NEON.CVAL.3.1006	When practicable, traceability to physical and biological standards shall be established via impartial standards organizations
NEON.CVAL.3.1007	When practicable, data products shall be compared using independent techniques
NEON.CVAL.3.1008	A laboratory data acquisition system shall simulate the field data logging system.
NEON.CVAL.3.1009	Data loggers and similar devices shall be validated prior to deployment and at least every 2 years using high accuracy NIST traceable digital multimeters, millivolt sources, and counters.
NEON.CVAL.3.1010	Triple point cells (Gallium (26.77165 °C) and Mercury (-38.83444 °C)) and an ice-water bath (0 °C) shall be used as a reference for calibration of all in situ (air, soil, and water) temperature sensors (e.g. platinum resistance thermometers) prior to deployment and at a minimum annually.
NEON.CVAL.3.1012	Soil and water temperature sensors shall be calibrated to achieve a 0.15 °C accuracy.

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