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| <i>Title:</i> NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | <i>Date:</i> 12/17/2019 |
| <i>NEON Doc. #:</i> NEON.DOC.000456 | <i>Author:</i> D. Durden, S. Metzger, J. Taylor, H. Loescher | <i>Revision:</i> E |

NEON SENSOR COMMAND, CONTROL AND CONFIGURATION (C3) DOCUMENT: EDDY-COVARIANCE TURBULENT EXCHANGE SUBSYSTEM

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See configuration management system for approval history.

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Change Record

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|----------|------------|-----------|--|
| A | 05/26/2016 | ECO-03881 | Initial release |
| B | 01/20/2017 | ECO-04356 | Adding IRGA DGD for extreme sites and new water trap |
| C | 09/12/2017 | ECO-04922 | Changing LI7200 timing configuration |
| D | 03-07/2019 | ECO-05977 | Adding MDP wordings |
| E | 12/17/2019 | ECO-06175 | Include CD07150010 as a valid pump part number |

TABLE OF CONTENTS

1 DESCRIPTION.....1

1.1 Purpose 1

1.2 Scope..... 1

2 RELATED DOCUMENTS AND ACRONYMS3

2.1 Applicable documents..... 3

2.2 Reference documents 4

3 ASSEMBLY, CSAT AND ELECTRONICS BOX INTRODUCTION (CD00370010 & CD06450000).....4

3.1 Introduction 4

3.2 Overview of sensor configuration..... 6

3.3 Command and control 6

3.3.1 Error handling 6

3.3.2 Sensor switched heating controls specification..... 6

4 ATTITUDE AND MOTION REFERENCE SYSTEM (CD00370100).....11

4.1 Introduction 11

4.2 Overview of sensor configuration..... 12

4.3 Command and control 13

5 H₂O AND CO₂ CONCENTRATION MEASUREMENT (CD00380100, CD00380110, CD06640003, CD06640004, CD06450000, & CA07190000)13

5.1 Introduction 14

5.2 Overview of sensor configuration..... 16

5.3 Command and control 16

5.3.1 Error handling 21

5.3.2 Sampling mode controls specification 21

5.3.3 Field validation controls specification..... 21

5.3.4 Leak test controls specification..... 23

5.3.5 Intake tube continuous heating controls specification..... 25



| | | |
|---|---|------------------|
| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

- 5.3.6 Rain cap switched heating controls specification 26
- 5.3.7 Water trap controls specification 26
- 6 VACUUM PUMP (CD07150000)27**
 - 6.1 Introduction 27
 - 6.2 Overview of sensor configuration..... 27
 - 6.3 Command and control 28
 - 6.3.1 Error handling 28
 - 6.3.2 Controls specification..... 28
- 7 MASS FLOW CONTROLLERS (CA11460000 & 0341500000).....28**
 - 7.1 Introduction 28
 - 7.2 Overview of sensor configuration..... 28
 - 7.3 Command and control 29
 - 7.3.1 Error handling 29
 - 7.3.2 Controls specification..... 29
- 8 GAS CYLINDER PRESSURE SENSORS (CA07160000 &CA07170000)29**
 - 8.1 Introduction 29
 - 8.2 Overview of sensor configuration..... 30
 - 8.3 Command and control 30
 - 8.3.1 Error handling 30
 - 8.3.2 Gas cylinder pressure sensor controls specification..... 30
- 9 APPENDIX.....32**
 - 9.1 List of Level 0 data product..... 32
 - 9.2 Validation and verification Tests – attitude and motion reference system 54
 - 9.3 Problem tracking and resolution 54
 - 9.4 Assembly schematic drawing..... 55
 - 9.5 Acronyms 55
 - 9.6 Functions..... 55
 - 9.7 Parameters..... 56
 - 9.8 Subscripts..... 56
 - 9.9 Variables..... 56



| | | |
|--|--|-------------------------|
| <i>Title:</i> NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | <i>Date:</i> 12/17/2019 |
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10 BIBLIOGRAPHY57

LIST OF TABLES AND FIGURES

| | |
|---|----|
| Table 1. Current design of sensors and other infrastructure used in the EC-TES, including DGD Agile part number, DGD Agile description, NEON part number and firmware version. | 1 |
| Table 2. List of L0 DPs that are acquired from the SONIC and its heater. Please note that the heater flag and its associated L0 DP are communicated and received from DGD CD06450000 (see Sect. 3.3.2). | 4 |
| Table 3. SONIC default configuration settings. | 6 |
| Table 4. Truth table to control SONIC heater for ice buildup. | 7 |
| Table 5. List of L0 DPs that are acquired from the attitude and motion reference sensor. | 11 |
| Table 6. Default configuration settings for the MTi-300-AHRS attitude and motion reference sensor. | 13 |
| Table 7. List of L0 DPs that are produced by the LI-7200. | 14 |
| Table 8. Infrared gas analyzer default configuration settings. Because these are sensor settings, tolerances are not available. | 16 |
| Table 9. List of L0 DPs related to LI-7200 operation modes and switched rain cap heating. | 17 |
| Table 10. List of settings and corresponding status during the three principal modes of LI-7200 operation. | 19 |
| Table 11. Configuration of the sampling mode. | 21 |
| Table 12. Configuration of the field validation. | 23 |
| Table 13. Configuration of the leak testing. | 24 |
| Table 14. Configuration of the continuous intake tube heating. | 25 |
| Table 15. Truth table to control the switched rain cap heater. | 26 |
| Table 16. Truth table to control the water trap. | 27 |
| Table 17. Configuration of the vacuum pump. | 27 |
| Table 18. Truth table to control the vacuum pump. | 28 |
| Table 19. Sampling and validation mass flow controller configuration settings. | 28 |
| Table 20. Default sensor configuration settings for the gas cylinder pressure sensor. | 30 |
| Table 21. Truth table for gas cylinder pressure. | 30 |
| Table 21. Validation and verification configuration settings for the Xsens MTi-300-AHRS. | 54 |
| Figure 1. The ‘double rotation’, first around the vertical axis z_m (left), then around the new transverse axis y (right). The attack angle α and the azimuth angle Ψ are shown. The transformation for the x-axis progresses from x_m over the intermediate step x_i to x in streamline coordinates (modified after Foken, 2008). | 8 |
| Figure 2. The CSAT3 native coordinate system (modified after Campbell Scientific, 2011). | 9 |
| Figure 3. Gas handling of the IRGA field validation system. The red and green dashed frames show the operational parts during sampling and validation mode, respectively. | 22 |
| Figure 4. Gas handling of the IRGA field validation system. The green, orange and black dashed frames show the system components during a series of automated leak tests, and the green dashed frame shows the system components during a manual leak test. | 25 |

1 DESCRIPTION

NEON will measure the exchange of momentum, energy and trace gases between the earth’s surface and the atmosphere. To accomplish this, NEON will operate an eddy-covariance turbulent exchange subsystem (EC-TES, a summary of all notation is provided in Sect. 9), which collectively embodies a suite of sensors.

1.1 Purpose

This document describes the command, control, and configuration (C³) details for operating the EC-TES at NEON terrestrial sites and Mobile Deployment Platform (MDP) sites. NEON can provide up to 5 MDP sites at a given period (together also called as “all NEON sites” or “NEON sites” below). MDP is a PI driven system; its site location varies depending on PI’s decision and research needs. This document includes a detailed discussion of all necessary requirements for operational control parameters, conditions/constraints, set points, and any necessary error handling. All Level 0 (L0) data products (DPs) generated by the sensors of the EC-TES are identified.

1.2 Scope

This C³ document is embedded in a series of existing and upcoming NEON documents, which collectively describe the acquisition, processing and quality control of data from the EC-TES (AD[01] provides an overview). As such, the scope of this C³ document is to specify all necessary command, control and configuration that enable acquiring high-quality L0 DPs from EC-TES sensors. In succeeding documents these L0 DPs are further processed into higher-level DPs. It is the current design that the sensors in Table 1 will be used in the EC-TES (AD[02]).

A complete set of the Level 0 data products generated in this document can be found in the appendix.

The Eddy-Covariance Turbulent Exchange Subsystem assembly will consist of the following Data Generating Device’s (DGDs) based on Data Generating Device DGD List and Hierarchies doc (AD [05]):

Table 1. Current design of sensors and other infrastructure used in the EC-TES, including DGD Agile part number, DGD Agile description, NEON part number and firmware version.

| DGD Agile PN | DGD Agile Description | Sensor | NEON PN | Firmware version |
|--------------|------------------------------------|--|--|------------------|
| CD00370010 | Assembly, CSAT and Electronics Box | Campbell Scientific CSAT3 3-D Sonic Anemometer with version 3.0f embedded code Manufacture part number: 28877 | 0300010000 (unheated). Heated version is TBD. | 3.0f |

| DGD Agile PN | DGD Agile Description | Sensor | NEON PN | Firmware version |
|--------------|---|--|------------|------------------|
| CD00370100 | Assembly, Accelerometer and Cable | Xsens attitude and motion reference system. Model number: MTi-300-2A5G4 | 0346850000 | N/A |
| CD00380100 | Assembly, ECTE Sensor Head and Analyzer | LI-COR LI-7200 infrared gas analyzer (includes LI-7200 sensor head and LI-7550 analyzer) | 0303030001 | 7.3.1 |
| CD00380110 | Assy, ECTE Sensor and Analyzer, Extreme Cold | LI-COR LI-7200 infrared gas analyzer (includes LI-7200 sensor head and LI-7550 analyzer) | 0303030001 | 7.3.1 |
| CD06640003 | Harness, Grape Digital Out, 5 Solenoid Control | N/A | CD06640003 | N/A |
| CD06640004 | Harness, Grape Digital Out, 5 Solenoid Control, 3 Foot | N/A | CD06640004 | N/A |
| CD06450000 | Harness, Grape Digital Out, Relay Control, environmental enclosure | N/A | CD06450000 | N/A |
| CA07190000 | Assembly, Transducer 0-30 PSI and Cable | Omega Engineering 0-30 psi Absolute Pressure Transducer (PT) 30 psi absolute pressure range, DIN connection style. Model number PX319-030AI. | 0335460000 | N/A |
| CD07150000 | Assembly, 24VDC Pump and Control | GAST Pump, Rotary Vane Vacuum, 24V DC Brushless, 7.2 Amp, 3000 RPM, 0.13 HP, 0.10 KW, 9 Lbs Gast Part No.: 2032-101-G644 | 0334770000 | N/A |
| CD07150010 | Assembly, Rebuilt 24VDC Pump and Controller | GAST Pump, Rotary Vane Vacuum, 24V DC Brushless, 7.2 Amp, 3000 RPM, 0.13 HP, 0.10 KW, 9 Lbs Gast Part No.: 2032-101-G644 | 0334770000 | N/A |
| CA11460000 | Controller, Mass Flow, Whisper Series Flow 0-20 SLPM w/ Display, ID | Alicat Controller, Mass Flow, Whisper Series Flow 0-20 SLPM w/ Display. | 0341480000 | N/A |

| DGD Agile PN | DGD Agile Description | Sensor | NEON PN | Firmware version |
|--------------|--|--|------------|------------------|
| | EEPROM, configured with Serial Output Default Frequency: 20Hz | Model: MCRW-20 SLPM-DS-NEON | | |
| 0341500000 | Controller, Mass Flow, 5 SLPM, ID Eeprom | Alicat Controller, Mass Flow, 5 SLPM. Model: MC-5 SLPM-NEON | 0341500000 | N/A |
| CA07160000 | Assembly, Transducer 0-100 psi and Cable Large | Barksdale Transducer Series 425 with Standard DIN connector, Pressure range 0-100 psi, 1/4-18 NPT male connect. Model number: 425T5-04 | 0327230000 | N/A |
| CA07170000 | Assembly, Transducer 0-3000 psi and Cable Large | Barksdale Transducer Series 425 with Standard DIN connector, Pressure range 0-3000 psi, 1/4-18 NPT male connector, Gauge pressure. Model number: 425T5-13 | 0327240000 | N/A |
| 0353710000 | Gas Cylinders, High Pressure, Internal Water Volume of 29.5 liters | N/A | | |

This C³ document first introduces related documents and conventions (Sect. 2). Followed by the C³ related to individual sensors of the EC-TES (Sects. 3–8). This document specifies the command, control, and configuration that are needed for operating these sensors and their associated heaters and infrastructure. It does not provide implementation details, except for cases where these stem directly from the sensor conditions as described here. Lastly, all notation used throughout the document is summarized in the appendix (Sect. 0)

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable documents

| | | |
|--------|-----------------|--|
| AD[01] | NEON.DOC.000573 | FIU Plan for Airshed QA/QC Development |
| AD[02] | NEON.DOC.000291 | NEON Configured Sensor List |
| AD[03] | NEON.DOC.005005 | NEON Level 0 Data Products Catalog |
| AD[04] | NEON.DOC.005004 | NEON Level 1–3 Data Products Catalog |

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| | | |
|--------|-----------------|---|
| AD[05] | NEON.DOC.000807 | Eddy-covariance Turbulent Exchange Subsystem Level 0 Prime Data Products ATBD |
| AD[06] | NEON.DOC.XXXXXX | Eddy-covariance Turbulent Exchange Sensor Maintenance Plan |
| AD[07] | NEON.DOC.001104 | Data Generating Device DGD List and Hierarchies |
| AD[08] | NEON.DOC.005003 | NEON Scientific Data Products Catalog |
| AD[09] | NEON.DOC.000001 | NEON Observatory Design (NOD) Requirements |
| AD[10] | NEON.DOC.003565 | Hut Gas Cylinder Configuration |

2.2 Reference documents

| | | |
|--------|-----------------|--|
| RD[01] | NEON.DOC.000008 | NEON Acronym List |
| RD[02] | NEON.DOC.000008 | NEON Glossary of Abbreviations |
| RD[03] | NEON.DOC.011071 | FIU Site Specific Sensor Location Matrix |

3 ASSEMBLY, CSAT AND ELECTRONICS BOX INTRODUCTION (CD00370010 & CD06450000)

3.1 Introduction

During NEON’s scientific justification process, the Campbell Scientific CSAT3 3-D sonic anemometer (SONIC) and thermometer (Campbell Scientific, 2011) was chosen for fast 3-D wind and temperature measurements at all NEON terrestrial sites and Mobile Deployment Platform (MDP) sites (Table 1).

Here, the command and control procedures and sensor configuration are described to enable the collection of all L0 DPs from the CSAT3 (AD[03]), which are required for the calculation of NEONs L1-L4 DPs (AD[04]) as well as the problem tracking and resolution (PTR).

The CSAT3 shall acquire data at a frequency of 20 Hz. For each datum, the RS–232 output from the CSAT3 consists of five 16 bit words. Each word is related either to a wind component, the sonic temperature, diagnostic values, measurement ranges, or a counter (Table 2). These data are output from the sensor in a binary format. This binary raw data is then collected and interpreted by the Data Acquisition System (DAS), and transmitted to NEON headquarters for processing. The heated version of the CSAT3 is a separate DGD that produces the same data streams as the non-heated plus additional PRT temperature measurements outlined in Table 2. The heater status flag will be sent by DGD CD06450000.

Table 2. List of L0 DPs that are acquired from the SONIC and its heater. Please note that the heater flag and its associated L0 DP are communicated and received from DGD CD06450000 (see Sect. 3.3.2).

| Data product | Data Format | Units | DP ID |
|---------------------|-------------|-------------------|---|
| SONIC | | | |
| Measured along-axis | IEEE 754 | m s ⁻¹ | NEON.DOM.SITE.DP0.00007.001.01927.HOR.VER.000 |

| Data product | Data Format | Units | DP ID |
|---|---|-------------|---|
| wind speed (u_m) | | | |
| Measured cross-axis wind speed (v_m) | IEEE 754 | $m\ s^{-1}$ | NEON.DOM.SITE.DP0.00007.001.01928.HOR.VER.000 |
| Measured vertical-axis wind speed (w_m) | IEEE 754 | $m\ s^{-1}$ | NEON.DOM.SITE.DP0.00007.001.01929.HOR.VER.000 |
| Measured speed of sound in air (c_m) | IEEE 754 | $m\ s^{-1}$ | NEON.DOM.SITE.DP0.00007.001.03048.HOR.VER.000 |
| Sample count | IEEE 754 | NA | NEON.DOM.SITE.DP0.00007.001.01930.HOR.VER.000 |
| Diagnostic values | 32 bit binary (16 leading zeroes followed by 16 bit binary) | NA | NEON.DOM.SITE.DP0.00007.001.02225.HOR.VER.000 |
| Additional stream for heated version | | | |
| Temperature transducer zone (top array) | IEEE 754 | $^{\circ}C$ | NEON.DOM.SITE.DP0.00007.001.01932.HOR.VER.000 |
| Temperature transducer zone (bottom array) | IEEE 754 | $^{\circ}C$ | NEON.DOM.SITE.DP0.00007.001.01935.HOR.VER.000 |
| Temperature base block | IEEE 754 | $^{\circ}C$ | NEON.DOM.SITE.DP0.00007.001.01936.HOR.VER.000 |
| Temperature top arm | IEEE 754 | $^{\circ}C$ | NEON.DOM.SITE.DP0.00007.001.01933.HOR.VER.000 |
| Temperature bottom arm | IEEE 754 | $^{\circ}C$ | NEON.DOM.SITE.DP0.00007.001.01934.HOR.VER.000 |

| Data product | Data Format | Units | DP ID |
|------------------------|--------------|-------|---|
| Heater status (on/off) | 1 bit binary | NA | NEON.DOM.SITE.DP0.00008.001.02221.HOR.VER.000 |

3.2 Overview of sensor configuration

The CSAT3 shall be operated with firmware version 3.0f at a data acquisition frequency of 20 Hz. Communication and data transfer with the CSAT3 shall be established using RS–232 serial communication. The RS–232 trigger will enable close synchronization with the H₂O and CO₂ concentration measurements (Sect. 5). Table 3 summarizes the default sensor configuration settings.

Table 3. SONIC default configuration settings.

| Parameter | Setting |
|--|---|
| Firmware version | 3.0f |
| Execution parameter | 20 Hz, configuration code Ah (60 Hz to 20 Hz oversampling mode) |
| Serial communication | RS–232 |
| Trigger source (to synchronize measurements) | PC trigger (RS–232 trigger from DAS) |
| Baud rate | 19,200 bps |
| Sampling mode | Three times oversample mode |
| Captured L0 DPs | Table 2 |

3.3 Command and control

3.3.1 Error handling

Error messages from the CSAT3 are encoded as 32 bit binary ‘Diagnostic values’ L0 DP (NEON.DOM.SITE.DP0.00007.001.01931.HOR.VER.000). Nine individual error messages are decoded in AD[05] and will be published as L1 DPs. These error messages will then be used for automated QA/QC algorithms and PTR assessment. Simplistic error handling should be implemented if any errors are received as a result of lost trigger (“No Data Available”, and “Lost Trigger” errors). The DAS shall attempt to re-establish the trigger.

3.3.2 Sensor switched heating controls specification

The climate at several NEON terrestrial sites can potentially cause the buildup of hoar frost or rime ice on the body, arms, and transducers of the SONIC. Ice buildup on the anemometer transducers obstructs the signal path, while ice buildup on the anemometer body and arms distorts the wind field. These conditions

lead to erroneous measurements by the SONIC. Minimizing the occurrence of these conditions can be achieved by selective sensor heating. There is a current design assumption that the sonic anemometer body and the transducer arms (but not the transducers itself) will have the ability to be heated. Based on this assumption we provide a general command and control structure to determine when the heating tube should be automatically switched on/off. The heating power shall be controlled through an operational feedback loop aiming at 40°C for the arithmetic mean of DP0.00007.001.01932 - DP0.00007.001.01936. The heater shall be turned off immediately if one of DP0.00007.001.01932 - DP0.00007.001.01936 exceeds 60°C, and a trouble ticket shall be sent to the PTR at NEON headquarters (HQ). All set points and below parameters shall be adjustable on a site-specific basis.

Only when there is ice buildup the heater shall be turned on. If the duration of sensor heating exceeds $t_2=6$ h in a window (trailing average) of $t_1=24$ h the heating shall be turned off and a trouble ticket shall be sent to PTR at NEON HQ. The status (on/off, LO DP DP0.00008.001.02221), which is the signal the LC is sending to the grape to control the heaters, shall be continuously recorded. This status cannot guarantee that the heaters are activated, it only provides confirmation that the command and control sequence has been initiated by the LC. In the following two automatic decision processes are constructed to switch on the heater when ice buildup is detected on (i) the transducers and (ii) the SONIC body and arms.

(i) To detect ice buildup on the transducers, the air temperature at tower top level from the HMP155 (T_{air} , LO DP DP0.00098.001.01358) and the CSAT3 diagnostic value (LO DP DP0.00007.001.01931), bit 12 (b_{12} , sonic signal amplitude too low) and bit 14 (b_{14} , poor signal lock) shall be used. Table 4 summarizes the conditions to switch the heater on/off, based on above DPs and shall be evaluated in the LC on-site.

Table 4. Truth table to control SONIC heater for ice buildup.

| Control parameter(s) | Condition | Data acquisition system action | Output to CI |
|--|--|--------------------------------|---|
| $\alpha, \Psi, \bar{\alpha}, \bar{\Psi}_i, b_{12}, b_{14}$ | if($b_{12}==0$ & $b_{14}==0$ & $\min(\bar{\alpha}(\min(\bar{\Psi}_i) < \Psi \leq \max(\bar{\Psi}_i))) \leq \alpha \leq \max(\bar{\alpha}(\min(\bar{\Psi}_i) < \Psi \leq \max(\bar{\Psi}_i)))$) | Turn heater off | DP0.00007.001.01927- DP0.00007.001.01931 |
| T_{air}, b_{12}, b_{14} | if($T_{air}+T_{zero} \leq 2^\circ\text{C}$ & ($b_{12}==1$ $b_{14}==1$)) | Turn heater on | DP0.00007.001.01927- DP0.00007.001.01931 |
| $T_{air}, \alpha, \Psi, \bar{\alpha}, \bar{\Psi}_i$ | if($T_{air}+T_{zero} \leq 2^\circ\text{C}$ & ($\alpha < \min(\bar{\alpha}(\min(\bar{\Psi}_i) < \Psi \leq \max(\bar{\Psi}_i)))$ $\alpha > \max(\bar{\alpha}(\min(\bar{\Psi}_i) < \Psi \leq \max(\bar{\Psi}_i)))$)) | Turn heater on | DP0.00007.001.01927- DP0.00007.001.01931 |

| | | | |
|------------|--|---|---|
| | $x(\bar{\alpha}(\min(\bar{\Psi}_i) < \Psi \leq \max(\bar{\Psi}_i)))$ | | |
| t_1, t_2 | if($t_2 > 0.25 t_1$) | Turn heater off, send trouble ticket to PTR at HQ | DP0.00007.001.01927- DP0.00007.001.01931 |

(ii) To detect ice buildup on the SONIC body and arms, a method based on monitoring of the flow angles is used. The specific method that will be used in NEON operations is still in the development stage. Here a method that uses the attack angle α and the azimuth angle (wind direction) Ψ is presented as a general guideline, and will be updated once the design of the EC-TES is finalized.

Under conditions close to the freezing point, the heater shall be turned on when measured α (180 min trailing average, evaluated every 10 min) departs from the range of values $\bar{\alpha}$ that are predefined for each wind sector $\bar{\Psi}_i$ (Table 4). These predefined $\bar{\alpha}, \bar{\Psi}_i$ are based on site-specific long-term averages. Thus they can only be provided once at least a full annual cycle of data is recorded, and are subject to change in time. Until then no predefined values can be supplied, and this part of the heater command and control shall be disabled. Nevertheless, to facilitate implementation of the necessary algorithms during the construction phase, we provide the required on-site calculations below.

The attack angle α and the azimuth angle Ψ define the transformation between the (assumed constant) SONIC coordinate system (x_m, y_m, z_m) and the streamline coordinate system (x, y, z , Figure 1). The orientation of the streamlines is a function of the surrounding terrain, and, to a lesser degree, of the instrument installation. If the instrument installation is significantly modified, e.g. due to ice buildup on the SONIC body or arms, the streamlines are affected. This change is indicated by altered flow angles, in particular by α due to the low magnitude of the average vertical wind. A threshold for a minimum wind speed may be necessary to prevent false flagging due low wind speeds.

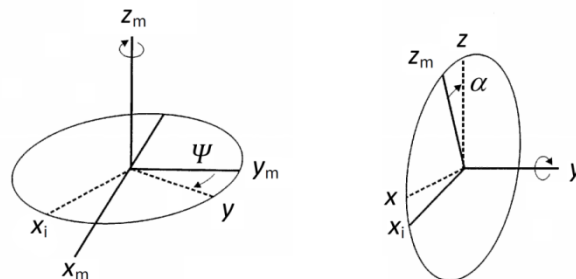


Figure 1. The ‘double rotation’, first around the vertical axis z_m (left), then around the new transverse axis y (right). The attack angle α and the azimuth angle Ψ are shown. The transformation for the x-axis progresses from x_m over the intermediate step x_i to x in streamline coordinates (modified after Foken, 2008).

To calculate the angles α , Ψ , the wind components in the CSAT3 coordinate system, u_m (LO DP DP0.00007.001.01927), v_m (LO DP DP0.00007.001.01928) and w_m (LO DP DP0.00007.001.01929) must be known. First the azimuth angle Ψ is calculated from 180 min trailing averages of along-axis $\overline{u_m}$ and transverse axis $\overline{v_m}$ wind components. The CSAT3 is defined in a right-hand coordinate system, with the x_m -axis pointing towards the instrument block (positive u_m when wind is blowing from the transducer arrays towards the instrument block), the y_m -axis pointing out of the plane (positive v_m when wind is blowing out of the plane), and the z_m -axis pointing upwards (positive w_m when wind is blowing upwards, Figure 2).

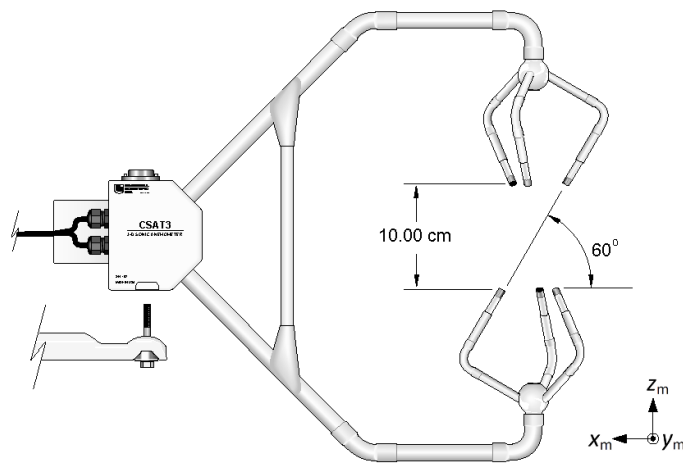


Figure 2. The CSAT3 native coordinate system (modified after Campbell Scientific, 2011).

The clockwise azimuth angle in the CSAT3 native coordinate system Ψ''' [rad] is derived by converting the horizontal wind vector $(\overline{u}_m, \overline{v}_m)$ into its polar form (e.g., Mori, 1986);

$$\Psi_3 = 2\pi - \left(\tan^{-1} \left(\frac{\overline{v}_m}{\overline{u}_m} \right) + X \right), \quad (1)$$

with the quadrant of the tangent function;

$$X = \begin{cases} 0 & \text{if } \overline{u}_m \geq 0 \ \& \ \overline{v}_m \geq 0, \\ \pi & \text{if } \overline{u}_m \leq 0 \ \& \ \overline{v}_m \geq 0, \\ \\ \pi & \text{if } \overline{u}_m \leq 0 \ \& \ \overline{v}_m \leq 0, \\ 2\pi & \text{if } \overline{u}_m \geq 0 \ \& \ \overline{v}_m \leq 0. \end{cases} \quad (2)$$

Now the projection has to be changed from the CSAT3 native coordinate system to the earth coordinate system. This is achieved by adding the clockwise positive azimuth angle offset (Ψ_0 [rad]) between true north (this value will be provided in the site specific as-built) and the sonic x_m -axis;

$$\Psi_2 = \Psi_3 + \Psi_0, \quad (3)$$

$$\Psi_1 = \begin{cases} \Psi_2 & \text{if } \Psi_2 < 2\pi, \\ \Psi_2 - 2\pi & \text{if } \Psi_2 \geq 2\pi. \end{cases}$$

Finally the resulting angle is converted from radians to decimal degree;

$$\Psi = \Psi_1 \frac{180}{\pi}. \quad (4)$$

Next the magnitude of the average horizontal wind vector in the x_m - y_m plane of the CSAT3 coordinate system, \overline{uv}_m , is determined as;

$$\overline{uv}_m = \sqrt{\overline{u}_m^2 + \overline{v}_m^2}. \quad (5)$$

Lastly, the value of the attack angle α is calculated;

$$\alpha = \tan^{-1} \frac{\overline{w}_m}{\overline{uv}_m}. \quad (6)$$

4 ATTITUDE AND MOTION REFERENCE SYSTEM (CD00370100)

4.1 Introduction

To correct boom/tower motions and changes in SONIC alignment during maintenance or sensor swaps, the Xsens MTi-300-AHRS attitude and motion reference sensor (Xsens Technologies, 2014) is deployed as part of the EC-TES (Table 1). The MTi-300-AHRS measures accelerations and rotation rates along 3 orthogonal axes, as well as the yaw angle. Using sensor fusion it internally derives pitch and roll angles, and outputs all variables to the data acquisition system (Table 5). Here, we describe the configuration, command and control related to the operation of this sensor.

Table 5. List of LO DPs that are acquired from the attitude and motion reference sensor.

| Data product | Data Format | Units | DP ID |
|--|-------------|------------------------------------|---|
| Measured along-axis inertial acceleration ($acc_{x,m}$) | IEEE 754 | $m\ s^{-2}$, positive forward | NEON.DOM.SITE.DP0.00010.001.02200.HOR.VER.000 |
| Measured cross-axis inertial acceleration ($acc_{y,m}$) | IEEE 754 | $m\ s^{-2}$, positive left | NEON.DOM.SITE.DP0.00010.001.02201.HOR.VER.000 |
| Measured vertical-axis inertial acceleration ($acc_{z,m}$) | IEEE 754 | $m\ s^{-2}$, positive up | NEON.DOM.SITE.DP0.00010.001.02202.HOR.VER.000 |
| Along-axis free acceleration | IEEE 754 | $m\ s^{-2}$, positive forward | NEON.DOM.SITE.DP0.00010.001.02203.HOR.VER.000 |
| Cross-axis free acceleration | IEEE 754 | $m\ s^{-2}$, positive left | NEON.DOM.SITE.DP0.00010.001.02204.HOR.VER.000 |
| Vertical-axis free acceleration | IEEE 754 | $m\ s^{-2}$, positive up | NEON.DOM.SITE.DP0.00010.001.02205.HOR.VER.000 |
| Pitch rate | IEEE 754 | $rad\ s^{-1}$, positive clockwise | NEON.DOM.SITE.DP0.00010.001.02206.HOR.VER.000 |

| | | | |
|---|------------------|--|---|
| Roll rate | IEEE 754 | rad s ⁻¹ , positive clockwise | NEON.DOM.SITE.DP0.00010.001.02207.HOR.VER.000 |
| Yaw rate | IEEE 754 | rad s ⁻¹ , positive clockwise | NEON.DOM.SITE.DP0.00010.001.02208.HOR.VER.000 |
| Measured pitch angle (θ_m) | IEEE 754 | Decimal degree | NEON.DOM.SITE.DP0.00010.001.02209.HOR.VER.000 |
| Measured roll angle (ϕ_m) | IEEE 754 | Decimal degree | NEON.DOM.SITE.DP0.00010.001.02210.HOR.VER.000 |
| Yaw angle | IEEE 754 | Decimal degree against magnetic north | NEON.DOM.SITE.DP0.00010.001.02211.HOR.VER.000 |
| Index | IEEE 754 | NA | NEON.DOM.SITE.DP0.00010.001.01930.HOR.VER.000 |
| Status word | 32 bit binary | NA | NEON.DOM.SITE.DP0.00010.001.02226.HOR.VER.000 |

4.2 Overview of sensor configuration

To ensure similar time-frequency resolution with wind and concentration measurements, a data acquisition frequency of 40 Hz shall be chosen. However, during validation and verification testing the MTi-300-AHRS may be operated with a data acquisition frequency of 400 Hz (Sect. 9.1). The default configuration settings for the MTi-300-AHRS are summarized in Table 6.

Table 6. Default configuration settings for the MTi-300-AHRS attitude and motion reference sensor.

| Parameter | Setting |
|------------------------------------|---|
| Sensor/Body coordinate system | forward-left-up (sensor-default) |
| Sensor/Reference coordinate system | east-north-up (ENU, sensor default) |
| Sensor/Misalignment | no misalignment |
| Sensor/GPS lever arm | no displacement |
| Heading reference | - |
| Motion profile | low mag_dep |
| Data Output/Status | status word |
| Data Output/Inertial Data | rate of turn, acceleration, free acceleration |
| Data Output/Orientation | Euler Angles |
| output frequency | 40 Hz |
| output configuration | trigger |
| protocol | MTI low-level |
| serial communication | RS-232 |
| baudrate | 115200 |
| data bits | 8 |
| parity | none |
| stop bits | 1 |
| flow control | disabled |
| Captured LO DPs | Table 5 |

4.3 Command and control

There is no command and control for the attitude and motion reference system.

5 H₂O AND CO₂ CONCENTRATION MEASUREMENT (CD00380100, CD00380110, CD06640003, CD06640004, CD06450000, & CA07190000)

During NEON’s scientific justification process, the LI-COR LI-7200 infrared gas analyzer (IRGA, LI-COR Inc., 2013) was chosen for the fast (turbulent-scale) measurement of H₂O and CO₂ concentrations at all NEON terrestrial and MDP sites (Table 1). Both the standard LI-7200 (CD00380100) and the extreme cold LI-7200 (CD00380110) are deployed with the exact same incoming data streams, sensor configurations, and command and control logic. The only difference between these sensor is the cold shifted calibration applied to the extreme cold LI-7200 (CD00380110); thus, only one set of sensor configurations and command and control are outlined below. The extreme cold LI-7200 is currently planned to be deployed at 5 NEON terrestrial sites in Alaska (BARR, BONA, DEJU, HEAL, TOOL) and Niwot Ridge, CO (NIWO). If additional fast-response gas analyzers will be added in the future, this document will be revised accordingly. All infrastructure required to perform sampling and validation is outlined in the subsequent sections.

5.1 Introduction

The fast H₂O and CO₂ concentration measurement are collected through the combination of an optical sample cell in the LI-7200 sensor head, and a separate electronics box that performs the digital signal processing (LI-7550 analyzer). Here, the command and control procedures and the sensor configuration are described that enable the collection of all L0 DPs from the LI-7200 (AD[03]) which are required for the calculation of NEONs higher level DPs (AD[04]) as well as the PTR of H₂O dry mole fraction and CO₂ dry mole fraction.

The LI-7200 shall sample data at a frequency of 20 Hz. Table 7 summarizes the data that are output by the LI-7200 and shall be acquired as L0 DPs (AD[03]). Measurements of thermodynamic properties, H₂O and CO₂ are output as floating point values (IEEE 754 format), whereas the LI-7200 diagnostic value is output as 16 bit binary.

Table 7. List of L0 DPs that are produced by the LI-7200.

| DP | Data Format | Units | DP ID |
|--|-------------|-------|---|
| Thermodynamic | | | |
| Cell temperature in (at sensor head inlet) | IEEE 754 | °C | NEON.DOM.SITE.D P0.00016.001.0217 8.HOR.VER.000 |
| Cell temperature out (at sensor head outlet) | IEEE 754 | °C | NEON.DOM.SITE.D P0.00016.001.0217 9.HOR.VER.000 |
| Block temperature | IEEE 754 | °C | NEON.DOM.SITE.D P0.00016.001.0218 0.HOR.VER.000 |
| Ambient pressure (LI-7550 box pressure) | IEEE 754 | kPa | NEON.DOM.SITE.D P0.00016.001.0218 1.HOR.VER.000 |
| Head pressure (differential pressure head-box) | IEEE 754 | kPa | NEON.DOM.SITE.D P0.00016.001.0217 8.HOR.VER.000 |
| H₂O | | | |
| H ₂ O sample power | IEEE 754 | W | NEON.DOM.SITE.DP 0.00016.001.02182. HOR.VER.000 |
| H ₂ O reference power | IEEE 754 | W | NEON.DOM.SITE.DP 0.00016.001.02183. HOR.VER.000 |

| | | | |
|---|---------------|------------------------|---|
| H ₂ O raw absorptance | IEEE 754 | Dimensionless ratio | NEON.DOM.SITE.DP 0.00016.001.02184. HOR.VER.000 |
| H ₂ O molar density | IEEE 754 | mmol m ⁻³ | NEON.DOM.SITE.DP 0.00016.001.02185. HOR.VER.000 |
| H ₂ O mixing ratio (dry mole fraction) | IEEE 754 | mmol mol ⁻¹ | NEON.DOM.SITE.DP 0.00016.001.02186. HOR.VER.000 |
| CO₂ | | | |
| CO ₂ sample power | IEEE 754 | W | NEON.DOM.SITE.DP 0.00016.001.02186. HOR.VER.000 |
| CO ₂ reference power | IEEE 754 | W | NEON.DOM.SITE.DP 0.00016.001.02187. HOR.VER.000 |
| CO ₂ raw absorptance | IEEE 754 | Dimensionless ratio | NEON.DOM.SITE.DP 0.00016.001.02188. HOR.VER.000 |
| CO ₂ molar density | IEEE 754 | mmol m ⁻³ | NEON.DOM.SITE.DP 0.00016.001.02189. HOR.VER.000 |
| CO ₂ mixing ratio (dry mole fraction) | IEEE 754 | μmol mol ⁻¹ | NEON.DOM.SITE.DP 0.00016.001.02190. HOR.VER.000 |
| Diagnostic values | | | |
| Sequence number | IEEE 754 | NA | NEON.DOM.SITE.DP 0.00016.001.01930. HOR.VER.000 |
| LI-7200 diagnostic value | 16 bit binary | NA | NEON.DOM.SITE.DP 0.00016.001.01931. HOR.VER.000 |
| LI-7200 diagnostic value 2 (sync clocks) | 1 bit binary | NA | NEON.DOM.SITE.DP 0.00016.001.02192. HOR.VER.000 |
| LI-7200 cooler voltage | IEEE 754 | V | NEON.DOM.SITE.DP 0.00016.001.02193. HOR.VER.000 |
| CO ₂ signal strength | IEEE 754 | % | NEON.DOM.SITE.DP 0.00016.001.02194. HOR.VER.000 |
| H ₂ O signal strength | IEEE 754 | % | NEON.DOM.SITE.DP 0.00016.001.02195. HOR.VER.000 |

5.2 Overview of sensor configuration

The LI-7200 shall communicate with the location controller via Ethernet at a data acquisition frequency of 20 Hz. Ethernet PTP version 1 shall be used to synchronize the measurements to the location controller to within 10 ms accuracy and 1 ms precision (LI-COR Inc., 2013). Table 8 summarizes the default sensor configuration settings, which must also be captured for each sensor as metadata. If there is a power failure (and maybe in other unforeseen circumstances), the LI-7200 shall be remotely reset to the default sensor configuration settings, either manually or automatically.

Table 8. Infrared gas analyzer default configuration settings. Because these are sensor settings, tolerances are not available.

| Parameter | Setting |
|-----------------------------|--------------------|
| Data collection rate | 20 Hz |
| Bandwidth setting | 10 Hz |
| Firmware version | 7.3.1* |
| SONIC input | Not used |
| Data communication | Ethernet |
| Captured L0 DPs | Table 7 |
| Update rate | 20 Hz |
| Data labels | Off |
| Diagnostic text records | Off |
| Length of data files | 3600 s |
| Clock sync (PTP) | Slave Only |
| Chopper housing temperature | 30°C |
| Delay step increment | 12 steps == 210 ms |
| Temperature reference | Onboard sensor |
| Pressure reference | Onboard sensor |

*The version of LI-COR software on laptops used for maintenance shall be kept compatible with the LI-7200 firmware.

5.3 Command and control

The current design requires the EC-TES to be operated in three modes, (i) sampling of ambient air, (ii) field validation and (iii) leak testing. In the following we describe the command and control of these operation modes, as well as the continuous heating of the intake tube, the switched heating of the rain cap, validation tube heating, SONIC heating, and water trap operation. For these purposes solenoid valves, a vacuum pump (Sect. 6), flow controllers (Sect. 7), and gas pressure sensors (Sect. 8) are used. Their default settings, command and control is provided in respective sections. Regardless of the mode of operation, all DPs in Table 9 shall be recorded continuously, at 0.2 Hz and 1 Hz, respectively.

Table 9. List of LO DPs related to LI-7200 operation modes and switched rain cap heating.

| DP | Data format | Units | DP ID |
|--|--------------|------------|---|
| General | | | |
| Vacuum pump voltage | IEEE 754 | volt | NEON.DOM.SIT E.DP0.00116.00 1.02351.HOR.V ER.000 |
| Sampling / validation solenoid status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02199.HOR.V ER.000 |
| Sampling | | | |
| Sampling mass flow rate set point (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00012.00 1.01952.HOR.V ER.000 |
| Sampling mass flow rate (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00012.00 1.01951.HOR.V ER.000 |
| Sampling volumetric flow rate (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00012.00 1.01950.HOR.V ER.000 |
| Sampling gas pressure (Absolute) (Alicat MCRW, Sect. 0) | IEEE 754 | kilopascal | NEON.DOM.SIT E.DP0.00012.00 1.01948.HOR.V ER.000 |
| Sampling gas temperature (Alicat MCRW, Sect. 0) | IEEE 754 | °C | NEON.DOM.SIT E.DP0.00012.00 1.01949.HOR.V ER.000 |
| Field validation | | | |
| Validation mass flow rate set point (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00015.00 1.01952.HOR.V ER.000 |
| Validation mass flow rate (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00015.00 1.01951.HOR.V ER.000 |
| Validation volumetric flow rate (Alicat MCRW, Sect. 0) | IEEE 754 | LPM | NEON.DOM.SIT E.DP0.00015.00 |

| | | | |
|--|--------------|-----|--|
| | | | 1.01950.HOR.V ER.000 |
| Validation gas pressure (Absolute) (Alicat MCRW, Sect. 0) | IEEE 754 | kPa | NEON.DOM.SIT E.DP0.00015.00 1.01948.HOR.V ER.000 |
| Validation gas temperature (Alicat MCRW, Sect. 0) | IEEE 754 | °C | NEON.DOM.SIT E.DP0.00015.00 1.01949.HOR.V ER.000 |
| Validation gas 1–5 hut solenoid status (on / off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00011.00 1.02212.HOR.V ER.000 - NEON.DOM.SIT E.DP0.00011.00 1.02216.HOR.V ER.000 |
| Validation gas 1–5 NEMA solenoid status enclosure (on / off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00009.00 1.02212.HOR.V ER.000 - NEON.DOM.SIT E.DP0.00009.00 1.02216.HOR.V ER.000 |
| Validation gas 1–5 cylinder pressure (gage) (Omega PX-329-3KG5V, Sect. 8) | IEEE 754 | kPa | NEON.DOM.SIT E.DP0.00034.00 1.02196.HOR.V ER.000 (separated by HOR 001-005) |
| Validation gas 1–5 delivery pressure (gage) (Omega PX-329-100G5V, Sect. 8) | IEEE 754 | kPa | NEON.DOM.SIT E.DP0.00035.00 1.02196.HOR.V ER.000 (separated by HOR 001-005) |
| Validation gas path heater status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02224.HOR.V ER.000 |
| Heating | | | |

| | | | |
|---|--------------|-----|---|
| Continuous intake tube heater status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02222.HOR.V ER.000 |
| Switched rain cap heater status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02223.HOR.V ER.000 |
| Water trap | | | |
| Pressure (gage) water trap (p_{trap}) | IEEE 754 | kPa | NEON.DOM.SIT E.DP0.00036.00 1.02196.HOR.V ER.000 |
| Water trap inlet valve status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02197.HOR.V ER.000 |
| Water trap vent valve status (on/off) | 1 bit binary | NA | NEON.DOM.SIT E.DP0.00008.00 1.02198.HOR.V ER.000 |

Table 10 provides an overview of settings and corresponding status during the three principal modes of LI-7200 operation.

Table 10. List of settings and corresponding status during the three principal modes of LI-7200 operation.

| DP | DP ID | Sampling mode | Validation mode | | | | | Leak test mode | | | |
|--|---|---------------|-----------------|--------|--------|--------|--------|----------------|---------|---------|--------|
| | | | Ga s 1 | Ga s 2 | Ga s 3 | Ga s 4 | Ga s 5 | Tes t 1 | Tes t 2 | Tes t 3 | Test 4 |
| Sampling / validation solenoid status (on/off) | NEON.DOM.SIT E.DP0.00008.0 01.02199.HOR. VER.000 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |
| Validation gas 1 status hut (on / off) | NEON.DOM.SIT E.DP0.00011.0 01.02212.HOR. VER.000 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 2 status hut (on / off) | NEON.DOM.SIT E.DP0.00011.0 01.02213.HOR. VER.000 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |



| | | |
|---|---|------------------|
| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

| | | | | | | | | | | | |
|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Validation gas 3 status hut (on / off) | NEON.DOM.SIT E.DPO.00011.0 01.02214.HOR. VER.000 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 4 status hut (on / off) | NEON.DOM.SIT E.DPO.00011.0 01.02215.HOR. VER.000 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 5 status hut (on / off) | NEON.DOM.SIT E.DPO.00011.0 01.02216.HOR. VER.000 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Validation gas 1 status NEMA (on / off) | NEON.DOM.SIT E.DPO.00009.0 01.02212.HOR. VER.000 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 2 status NEMA (on / off) | NEON.DOM.SIT E.DPO.00009.0 01.02213.HOR. VER.000 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 3 status NEMA (on / off) | NEON.DOM.SIT E.DPO.00009.0 01.02214.HOR. VER.000 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 4 status NEMA (on / off) | NEON.DOM.SIT E.DPO.00009.0 01.02215.HOR. VER.000 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Validation gas 5 status NEMA (on / off) | NEON.DOM.SIT E.DPO.00009.0 01.02216.HOR. VER.000 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Validation gas path heater status (on/off) | NEON.DOM.SIT E.DPO.00008.0 01.02224.HOR. VER.000 | 0 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0 | 0 | 0 | 0 |
| Continuous intake tube heater status (on/off) | NEON.DOM.SIT E.DPO.00008.0 01.02222.HOR. VER.000 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 |
| Switched rain cap heater status (on/off) | NEON.DOM.SIT E.DPO.00008.0 01.02223.HOR. VER.000 | 0/1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

5.3.1 Error handling

Error messages from the LI-7200 are encoded as 16 bit binary diagnostic value L0 DP. Ten individual error messages will be subsequently decoded in the respective ATBD (AD[05]), and will be provided as a L1 DPs. These error messages will then be used for PTR as well as for automated QA/QC algorithms. No additional automatic/programmed queries are needed to determine any other error in function.

5.3.2 Sampling mode controls specification

The IRGA field validation system consists of an array of gas supplies, valves and sensors, which integrates all three modes of operation into one single design (Figure 3). During sampling the vacuum pump pulls air from the IRGA intake, which passes through the IRGA optical cell and subsequently by the water trap (Figure 3, red dashed frame). The settings and corresponding status of individual infrastructure parts are summarized in Table 10 and Table 11.

Table 11. Configuration of the sampling mode.

| Parameter | Default Setting |
|---|-----------------|
| Vacuum pump status | On |
| Sampling mass flow controller set point | 12 SLPM |

5.3.3 Field validation controls specification

Field validation is performed to periodically monitor and assess IRGA absorptance zero drift (H₂O and CO₂), as well as the IRGA zero coefficient (H₂O and CO₂) and span coefficient (CO₂). To perform the field validation, gas cylinders containing zero-air gas as well as four known CO₂ concentrations are used. Related L0 DPs in Table 9 shall be recorded continuously. The field validation shall be performed automatically at predefined time intervals. In addition it shall be possible to trigger a validation cycle manually during site routine maintenance. During field validation the validation gas supply J3 shall be connected to the IRGA optical cell and vented through the IRGA intake (Figure 3, green frame). We anticipate the total volume in all of the gas handling in the field validation system to be $\approx 1.5 \cdot 10^{-4} \text{ m}^3$ or 0.15 L (7.5 m of 0.0048 m ID tubing, optical cell, valves and manifolds). This volume shall be purged until the rate of change of absorptance of H₂O and CO₂ (L0 DP NEON.DOM.SITE.DP0.00016.001.02184.HOR.VER.000, NEON.DOM.SITE.DP0.00016.001.02189.HOR.VER.000) falls below $5 \cdot 10^{-5} \text{ s}^{-1}$ for a trailing 2 min average. We anticipate approximate equilibrium after ≈ 35 purges of the system volume, corresponding to ≈ 3.5 min flushing at a flow rate of $\approx 1.5 \text{ L min}^{-1}$. After equilibrium is reached, the supply of validation gas shall continue for another 1.5 min, during which period the data for the actual field validation is collected. The validation cycle for each validation gas lasts 5 min, including the times for purging and acquisition of valid field validation data. The cycle shall be carried out, in sequence, for zero gas, three validation gases from

lowest to highest concentration, and zero gas. The entire validation cycle lasts 25 min, and every 164.5 h a fifth gas standard (high-accuracy long time standard) shall be added to the end of the validation cycle, extending the overall duration to 30 min. The field validation is performed on a fixed-date basis, every 23.5 h with respect to Coordinated Universal Time, regardless of the system being subjected to downtime between field validations. A field validation starts either at the beginning of the hour (00:00.00) or the beginning of the half-hour (30:00.00). The combination of valve activations will be used to determine the leak test or validation cycle that is being performed in the L0 prime ATBD ([AD 05]).

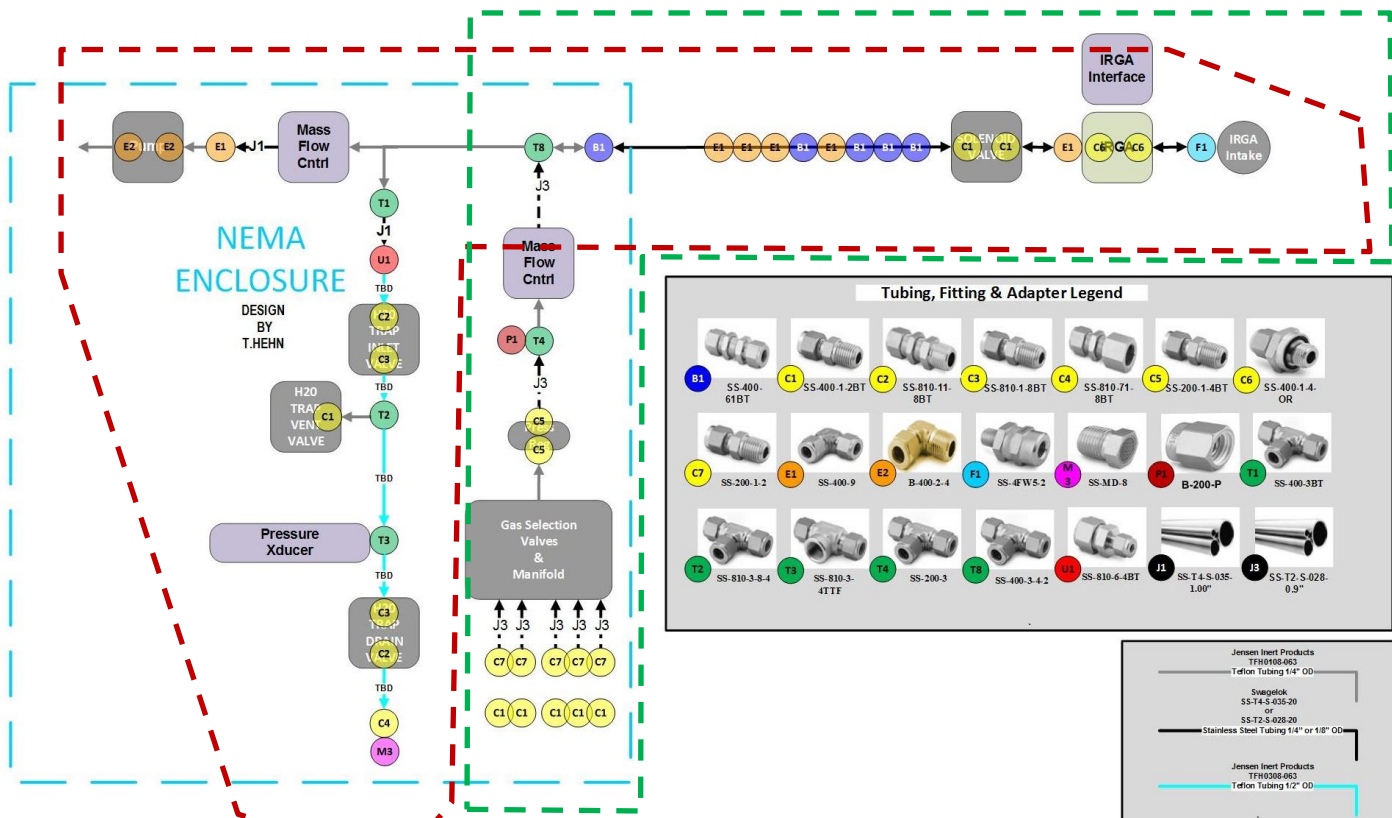


Figure 3. Gas handling of the IRGA field validation system. The red and green dashed frames show the operational parts during sampling and validation mode, respectively.

The sampling mode (Sect. 5.3.1) shall resume immediately after the last validation standard is measured. It is the current assumption that it will take substantially less than one minute for the gas plumbing to reach sampling steady-state, thus no more than 30 min of continuous data coverage is lost. The configuration for this validation cycle is summarized in Table 12 and the settings and corresponding status of individual infrastructure parts is summarized in Table 10.

Table 12. Configuration of the field validation.

| Parameter | Default Setting |
|---|--|
| Validation recurrence | Every 23.5 h (routine validation) and 164.5 h (high-accuracy long term standard) with respect to Coordinated Universal Time, regardless of the system being subjected to downtime between field validations |
| Overall duration | 25 min (routine validation), 30 min (including high-accuracy long term standard) |
| Vacuum pump status | Off |
| Validation gas standards | Zero gas and three gas standards for routine validation, one high-accuracy long term standard |
| Duration for each validation gas standard | 5 min |
| Validation mass flow rate set point | 1.5 LPM |
| Validation gas path heater | Control gas temperature such that IRGA head inlet temperature (LO DP NEON.DOM.SITE.DPO.00016.001.02178.HOR.VER.000) during field validation differs <3°C from the IRGA head outlet temperature (LO DP NEON.DOM.SITE.DPO.00016.001.02179.HOR.VER.000) from the preceding sampling mode. Both temperatures used for control are derived using a 60 s trailing average. |

5.3.4 Leak test controls specification

Leak testing of the IRGA gas plumbing system can be performed through applying a vacuum to individual system components. Two principal modes of leak tests are available, (i) an automated leak test and (ii) a manual leak test.

During the automated leak test, air is plumbed identical to the sampling mode (Sect. 5.3.1), i.e. the vacuum pump pulls air from the IRGA intake, which passes through the IRGA optical cell and subsequently by the water trap. In this configuration, several solenoids are switched in a predefined sequence to isolate individual parts of the gas plumbing:

1. Vacuum pump to solenoid (Figure 4, red dashed frame);
2. Vacuum pump to solenoid, including water trap (Figure 4, orange dashed frame);
3. Vacuum pump to solenoid, including validation gas selection manifold (Figure 4, black dashed frame);

The settings and corresponding status of individual infrastructure parts is summarized in Table 10. Each time that a routine field validation is performed (i.e., every time that no high-accuracy long time standard is used, Sect. 0), the automated leak test sequence 1.–3. shall be added to the end of the validation cycle.

The automated leak test sequence 1.–3. shall take no longer than 5 min, extending the overall duration of field validation and automated leak test to 30 min. During the automated leak test sequence the water trap will be opened for 30 seconds to drain any accumulated water (see Sect. 5.3.7), it can be performed at any time except during Test 2 (see Table 13). The sampling mode (Sect. 5.3.1) shall resume immediately after the automated leak test sequence is completed.

Every time after part of the IRGA gas plumbing system was disassembled (e.g., intake filter change), in addition to the automated leak test sequence 1.–3., a manual leak test is performed:

4. Vacuum pump to rain cap (Figure 4, green dashed frame).

The settings and corresponding status of individual infrastructure parts are summarized in Table 10 and Table 13.

Table 13. Configuration of the leak testing.

| Parameter | Default Setting |
|---|--|
| Recurrence of automated leak test sequence (Test 1–3) | Every 23.5 h immediately following routine validation sequence, but not at 164.5 h (validation sequence including high-accuracy long time standard validation) |
| Recurrence of manual leak test sequence (Test 1–4) | Every time after part of the IRGA gas plumbing system was disassembled (e.g., intake filter change) |
| Overall duration | 5 min (automated leak test), user-dependent (manual leak test) |
| Vacuum pump status | On |
| Sampling mass flow rate set point | 12 SLPM |
| Test 1 | Vacuum pump to solenoid (Figure 4, red dashed frame, Table 10) |
| Test 2 | Vacuum pump to solenoid, including water trap (Figure 4, orange dashed frame, Table 10) |
| Test 3 | Vacuum pump to solenoid, including validation gas selection manifold (Figure 4, black dashed frame, Table 10) |
| Test 4 | Vacuum pump to rain cap (Figure 4, green dashed frame, Table 10) |

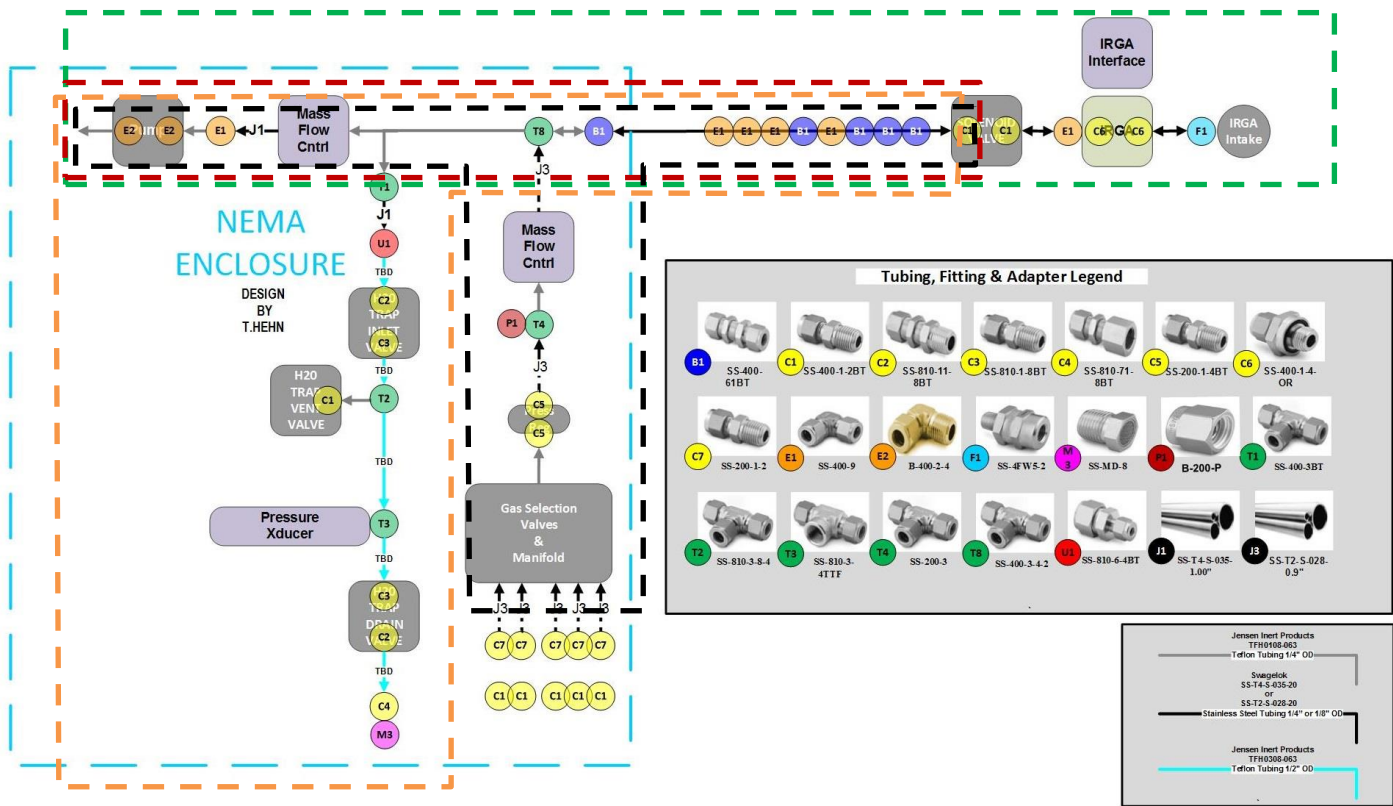


Figure 4. Gas handling of the IRGA field validation system. The green, orange and black dashed frames show the system components during a series of automated leak tests, and the green dashed frame shows the system components during a manual leak test.

5.3.5 Intake tube continuous heating controls specification

The intake tube consists of a 70 cm long stainless steel tube with 4.8 mm ID and a Swagelok FW 2 μm pleated mesh filter covering the atmosphere-side opening. The entire length of the intake tube is insulated (15 mm) and heated (Watlow #010300C1). Table 14 summarizes the configuration of the continuous intake tube heating.

Table 14. Configuration of the continuous intake tube heating.

| Parameter | Default Setting |
|---------------|-----------------|
| Recurrence | Continuous |
| Heating power | 4 W |

5.3.6 Rain cap switched heating controls specification

IRGA rain cap heating is enabled as function of differential pressure head-box (dp_{IRGA} , LO DP NEON.DOM.SITE.DP0.00016.001.02181.HOR.VER.000 $\cdot 10^3$), dew point temperature T_{H2O} (LO DP NEON.DOM.SITE.DP0.00098.001.01358.HOR.VER.000 $- T_{zero}$), and ambient temperature (T_{air} , LO DP NEON.DOM.SITE.DP0.00098.001.01309.HOR.VER.000).

These variables are evaluated using a continuous trailing 10 min average. If the heating duration exceeds $t_2=6$ h in a window (trailing average) of $t_1=24$ h the heating and the vacuum pump shall be turned off, and a trouble ticket shall be sent to PTR at NEON HQ. The heating controls are summarized in Table 15.

Table 15. Truth table to control the switched rain cap heater.

| Control parameter(s) | Condition | Data acquisition system action | Output to CI |
|-------------------------------|--|---|------------------------------------|
| $dp_{IRGA}, T_{air}, T_{H2O}$ | if($dp_{IRGA} > 2000$ Pa & $T_{air} < -T_{zero} + 3 \pm 1$ K & $T_{air} < T_{H2O} + 3 \pm 1$ K) | Turn heater on | Summarized in Table 9 and Table 10 |
| $dp_{IRGA}, T_{air}, T_{H2O}$ | if($dp_{IRGA} < 2000$ Pa $T_{air} > -T_{zero} + 3 \pm 1$ K $T_{air} > T_{H2O} + 3 \pm 1$ K) | Turn heater off | Summarized in Table 9 and Table 10 |
| t_1, t_2 | if($t_2 > 0.25 t_1$) | Turn heater and vacuum pump off, send trouble ticket to PTR at HQ | Summarized in Table 9 and Table 10 |

5.3.7 Water trap controls specification

The trap's inlet valve is normally open, the vent and drain valves are normally closed. The command and control for the water trap is performed during the automated leak test sequence. The water trap will be opened for 30 seconds to drain any accumulated water (see Sect. 5.3.4).

At sites where frequent water ingest occurs additional command and control may be performed to drain trap more frequently. In these cases, the pressure difference (p_{diff}) between the absolute pressures measured by the trap pressure sensor (DGD CA07190000) and the sampling mass flow controller (DGD CA11460000, see Sect. 7) (p_{trap} and p_{mfc}) indicates that the trap is nearly full ($p_{diff,max}=3$ kPa), (i) the inlet valve is closed, and (ii) the vent and drain valves are opened. If the pressure does not decrease with a rate $\Delta p_{trap}/\Delta t=60$ Pa s^{-1} or faster, or if the drain time t_{drain} exceeds $t_{drain,max}=600$ s, the pump is shut down and a

trouble ticket is issued. Once p_{diff} falls below $p_{diff,min}=0.1$ kPa, (i) the vent and drain valves are closed and (ii) the inlet is opened. Above parameter values are initial values, and will be updated in the CI data store.

Table 16. Truth table to control the water trap.

| Control parameter(s) | Condition | Data acquisition system action | Output to CI |
|--|--|---|-----------------------|
| p_{diff}, p_{max} | $p_{diff} > p_{diff,max}$ | Close inlet valve Open vent valve Open drain valve | Summarized in Table 9 |
| $\Delta p_{trap}/\Delta t, t_{drain}, t_{drain,max}$ | $\Delta p_{trap}/\Delta t < 60$ $\text{Pa s}^{-1} \mid t_{drain} > t_{drain,max}$ | Shut down pump Issue trouble ticket | Summarized in Table 9 |
| $p_{diff}, p_{diff,min}$ | $p_{diff} < p_{diff,min}$ | Close vent valve Close drain valve Open inlet valve | Summarized in Table 9 |

6 VACUUM PUMP (CD07150000 AND CD07150010)

6.1 Introduction

During sampling and leak testing modes, a vacuum pump is used to draw an air current through the IRGA sampling cell (Sect. 5.3, Table 9, Table 10). A GAST 2032-101-G644 oil-less rotary vane vacuum pump (GAST, accessed 2013) will be used for this purpose (Table 1). Here we describe the configuration, command and control related to the operation of this vacuum pump. The associated SOP document (AD[06]) explains the requirements for deployment and maintenance.

6.2 Overview of sensor configuration

DAS (LC) will control the pump speed through controlling the voltage signal sent to the pump. This voltage (0-5 volts) sent to pump will be streamed as L0 DPs and used for post- data process to generate system health flags. 0 volt means pump is stopped. The speed control voltage set point for the pump is 4 volts. Table 17 summarizes the configuration of the vacuum pump.

Table 17. Configuration of the vacuum pump.

| Parameter | Default Setting |
|--------------|------------------------|
| Power status | On, switchable via PDU |

6.3 Command and control

NA

6.3.1 Error handling

Switch off vacuum pump before overheating; send trouble ticket to PTR at HQ.

6.3.2 Controls specification

See Sect. 5.3. Additional controls are summarized in Table 18.

Table 18. Truth table to control the vacuum pump.

| Control parameter(s) | Condition | Data acquisition system action | Output to CI |
|----------------------|---------------------------------------|--|------------------------------------|
| dp_{IRGA} | $if(dp_{IRGA} \geq 10000 \text{ Pa})$ | Switch off vacuum pump, send trouble ticket to PTR at HQ | Summarized in Table 9 and Table 10 |

7 MASS FLOW CONTROLLERS (CA11460000 & 0341500000)

7.1 Introduction

Mass flow controllers are used to maintain and monitor a constant flow rate through the IRGA optical cell during sampling and validation configurations (Table 9, Table 10). The Alicat MCRW Series mass flow controller (Alicat Scientific, 2012) with 20 SLPM body and 20 SLPM full scale range will be used during sampling (Table 1). The Alicat MC Series mass flow controller (Alicat Scientific, 2012) with 5 SLPM full scale range will be used during validation cycles (Table 1). The mass flow controller will be operated with a data acquisition frequency of 20 Hz during sampling and 1 Hz during validation. Here, we describe the configuration, command and control related to the operation of these flow controllers. The associated SOP document (AD[06]) explains the requirements for calibration, deployment, maintenance and sensor exchanges.

7.2 Overview of sensor configuration

Sensor configuration settings are given in Table 19.

Table 19. Sampling and validation mass flow controller configuration settings.

| Sampling Mass Flow Controller (CA11460000) | |
|---|-----------------|
| Parameter | Default Setting |
| Interface | RS-232 |

| | |
|--|---|
| Baud rate | 19200 |
| Input/output | 8 data bits, no parity, 1 stop bit, no flow control |
| Control valve configuration | Downstream valve |
| Standard conditions for mass flow calculations | NIST standard conditions (293.15 K, 101.325 kPa) |
| Gas select | Air |
| PID parameters | Factory setting |
| Response time | 0.1 s |
| Positioning | Upright |
| Output frequency | 20 Hz |
| Validation Mass Flow Controller (034150000) | |
| Parameter | Default Setting |
| Interface | RS-232 |
| Baud rate | 19200 |
| Input/output | 8 data bits, no parity, 1 stop bit, no flow control |
| Control valve configuration | Upstream valve |
| Standard conditions for mass flow calculations | NIST standard conditions (293.15 K, 101.325 kPa) |
| Gas select | Air |
| PID parameters | Factory setting |
| Response time | 0.1 s |
| Positioning | Upright |
| Output frequency | 1 Hz |

7.3 Command and control

NA

7.3.1 Error handling

NA

7.3.2 Controls specification

See Sect. 5.3.

8 GAS CYLINDER PRESSURE SENSORS (CA07160000 &CA07170000)

8.1 Introduction

Pressure sensors are used to monitor (i) the pressure in the gas cylinders and (ii) the supply-side pressure after the pressure regulator for gas delivery to the associated sensors and (iii) line pressure (Table 9, Table

10). At this time, the Omega PX-319 series sensors (Omega, accessed 2013) will be used for these purposes (Table 1). Here, we describe the configuration, command and control related to the operation of this pressure sensor. A description of how sensor readings shall be converted to pressure units is provided in the associated ATBD (AD[05]). The associated SOP document (AD[06]) explains the requirements for calibration, field deployment, and maintenance.

8.2 Overview of sensor configuration

The acquisition rate from this sensor shall be 1 Hz. The default sensor configuration settings are given in Table 20. In the hut, the gas cylinder locations follow the specified layout in AD [8]. Locations from number 9 to 16 are assigned to the cylinders used for profile system.

Gas cylinders will be swapped by field techs when the gas cylinder pressure drops below 400 psig (2758 kPa). The gas concentration inside the cylinder may change during a cylinder swap. Therefore, the timestamp when the cylinder is swapped will be provided by field techs. The gas concentration and uncertainties for each cylinder will be provided by CVAL.

L0 data for the gas concentration and associated uncertainty for gas cylinders (DGD: 0353710000) will be extracted from CVAL XML file. It can be found in Appendix 9.1.

Table 20. Default sensor configuration settings for the gas cylinder pressure sensor.

| Parameter | Setting |
|------------|----------------------|
| Excitation | Analog, 9–30 V |
| Output | Analog, 0.004–0.02 A |

8.3 Command and control

NA

8.3.1 Error handling

NA

8.3.2 Gas cylinder pressure sensor controls specification

Table 21. Truth table for gas cylinder pressure.

| Control parameter(s) | Condition | Data acquisition system action | Flag output to CI as L0 DP |
|----------------------|---|---|----------------------------|
| Cylinder pressure | Cylinder pressure < 400 psig (2758 kPa) | Generate trouble ticket and send to field technician to swap gas cylinder | None |



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| <i>Title:</i> NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | <i>Date:</i> 12/17/2019 |
| <i>NEON Doc. #:</i> NEON.DOC.000456 | <i>Author:</i> D. Durden, S. Metzger, J. Taylor, H. Loescher | <i>Revision:</i> E |

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|---|---|------------------|
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9 APPENDIX

9.1 List of Level 0 data product

| DGD Agile PN | DPName | DPNumber | fieldName | description | Acquisition frequency (Hz) | dataType | units |
|--------------|--------|---|-----------|--|----------------------------|----------|-----------------|
| CD00370010 | soni | NEON.DOM.SITE.DP0.00007.001.01927.HOR.VER.000 | veloXaxs | Linear velocity (velo) of wind in 3-D sonic anemometer along-axis direction (Xaxs), positive backward | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01928.HOR.VER.000 | veloYaxs | Linear velocity (velo) of wind in 3-D sonic anemometer cross-axis direction (Yaxs), positive right | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01929.HOR.VER.000 | veloZaxs | Linear velocity (velo) of wind in 3-D sonic anemometer vertical-axis direction (Zaxs), positive upwards | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.03048.HOR.VER.000 | veloSoni | Linear velocity (velo) of sound (Soni) | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01930.HOR.VER.000 | idx | Index value (idx) | 20 Hz | integer | NA |
| | soni | NEON.DOM.SITE.DP0.00007.001.02225.HOR.VER.000 | diag16 | Diagnostic value (diag), output as a 16 bit integer Bit assignment according to NEON.DOC.000807 (LO prime processing ATBD) | 20 Hz | integer | NA |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|-----|------|---|----------|---|-------|---------|-----------------|
| TBD | soni | NEON.DOM.SITE.DP0.00007.001.01927.HOR.VER.000 | veloXaxs | Linear velocity (velo) of wind in 3-D sonic anemometer along-axis direction (Xaxs), positive backward | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01928.HOR.VER.000 | veloYaxs | Linear velocity (velo) of wind in 3-D sonic anemometer cross-axis direction (Yaxs), positive right | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01929.HOR.VER.000 | veloZaxs | Linear velocity (velo) of wind in 3-D sonic anemometer vertical-axis direction (Zaxs), positive upwards | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.03048.HOR.VER.000 | veloSoni | Linear velocity (velo) of sound (Soni) | 20 Hz | real | metersPerSecond |
| | soni | NEON.DOM.SITE.DP0.00007.001.01930.HOR.VER.000 | idx | Index value (idx) | 20 Hz | integer | NA |
| | soni | NEON.DOM.SITE.DP0.00007.001.02225.HOR.VER.000 | diag16 | Diagnostic value (diag), output as a 16 bit integer Bit assignment according to NEON.DOC.000807 (LO prime processing ATBD) | 20 Hz | integer | NA |
| | soni | NEON.DOM.SITE.DP0.00007.001.01936.HOR.VER.000 | tempBloc | Temperature (temp) of the instrument block (Bloc) measured by platinum resistance thermometers (heated 3-D sonic anemometer only) | ? | real | celsius |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|----------|---|-------------|---|-------|------|------------------------|
| | soni | NEON.DOM.SITE.DP0.00007.001.01933.HOR.VER.000 | tempArmTop | Temperature (temp) of the arm (Arm) top zone (Top) measured by platinum resistance thermometers (heated 3-D sonic anemometer only) | ? | real | celsius |
| | soni | NEON.DOM.SITE.DP0.00007.001.01934.HOR.VER.000 | tempArmBot | Temperature (temp) of the arm (Arm) bottom (Bot) zone measured by platinum resistance thermometers (heated 3-D sonic anemometer only) | ? | real | celsius |
| | soni | NEON.DOM.SITE.DP0.00007.001.01932.HOR.VER.000 | tempTranTop | Temperature (temp) of the transducer (Tran) top zone (Top) measured by platinum resistance thermometers (heated 3-D sonic anemometer only) | ? | real | celsius |
| | soni | NEON.DOM.SITE.DP0.00007.001.01935.HOR.VER.000 | tempTranBot | Temperature (temp) of the transducer (Tran) bottom zone (Bot) measured by platinum resistance thermometers (heated 3-D sonic anemometer only) | ? | real | celsius |
| CD00370100 | soniAmrs | NEON.DOM.SITE.DP0.00010.001.02200.HOR.VER.000 | acceXaxs | Linear acceleration (acce) in attitude and motion reference system along-axis | 40 Hz | real | metersPerSecondSquared |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|----------|---|--------------|--|---|-------|------|------------------------|
| | | | | direction (Xaxs), positive forward | | | |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02201.HOR.VER.000 | acceYaxs | | Linear acceleration (acce) in attitude and motion reference system along-axis direction (Yaxs), positive left | 40 Hz | real | metersPerSecondSquared |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02202.HOR.VER.000 | acceZaxs | | Linear acceleration (acce) in attitude and motion reference system vertical-axis direction (Zaxs), positive upwards | 40 Hz | real | metersPerSecondSquared |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02203.HOR.VER.000 | acceXaxsFree | | Linear acceleration (acce) in attitude and motion reference system along-axis direction (Xaxs), positive forward, after subtraction of acceleration due to earth's gravity (free) | 40 Hz | real | metersPerSecondSquared |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02204.HOR.VER.000 | acceYaxsFree | | Linear acceleration (acce) in attitude and motion reference system cross-axis direction (Yaxs), positive left, after subtraction of acceleration due to earth's gravity (free) | 40 Hz | real | metersPerSecondSquared |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|----------|---|--------------|--|-------|------|------------------------|
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02205.HOR.VER.000 | acceZaxsFree | Linear acceleration (acce) in attitude and motion reference system vertical-axis direction (Zaxs), positive upwards, after subtraction of acceleration due to earth's gravity (free) | 40 Hz | real | metersPerSecondSquared |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02206.HOR.VER.000 | omegYaxs | Angular velocity (omeg) around the attitude and motion reference system cross-axis (Yaxs), positive in clockwise direction, synonymous with pitch rate | 40 Hz | real | radiansPerSecond |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02207.HOR.VER.000 | omegXaxs | Angular velocity (omeg) around the attitude and motion reference system along-axis (Xaxs), positive in clockwise direction, synonymous with roll rate | 40 Hz | real | radiansPerSecond |
| soniAmrs | NEON.DOM.SITE.DP0.00010.001.02208.HOR.VER.000 | omegZaxs | Angular velocity (omeg) around the attitude and motion reference system vertical-axis (Zaxs), positive in clockwise direction, synonymous with yaw rate | 40 Hz | real | radiansPerSecond |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|----------|---|------------|---|-------|---------|---------|
| | soniAmrs | NEON.DOM.SITE.DP0.00010.001.02209.HOR.VER.000 | thetYaxs | Angle (thet) around the attitude and motion reference system cross-axis (Yaxs), positive in clockwise direction, synonymous with pitch angle | 40 Hz | real | degree |
| | soniAmrs | NEON.DOM.SITE.DP0.00010.001.02210.HOR.VER.000 | thetXaxs | Angle (thet) around the attitude and motion reference system along-axis (Xaxs), positive in clockwise direction, synonymous with roll angle | 40 Hz | real | degree |
| | soniAmrs | NEON.DOM.SITE.DP0.00010.001.02211.HOR.VER.000 | thetZaxs | Angle (thet) around the attitude and motion reference system vertical-axis (Zaxs), positive in clockwise direction, synonymous with yaw angle | 40 Hz | real | degree |
| | soniAmrs | NEON.DOM.SITE.DP0.00010.001.01930.HOR.VER.000 | idx | Index value (idx) | 20 Hz | integer | NA |
| | soniAmrs | NEON.DOM.SITE.DP0.00010.001.02226.HOR.VER.000 | diag32 | Diagnostic value (diag), output as 32-bit integer Bit assignment according to NEON.DOC.000807 (LO prime processing ATBD) | 40 Hz | integer | NA |
| CD00380100 | irga | NEON.DOM.SITE.DP0.00016.001.02178.HOR.VER.000 | tempCellIn | Temperature (temp) of the optical cell (Cell) inlet (In) thermocouple | 20Hz | real | celsius |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------|---|--------------|--|------|------|------------|
| irga | NEON.DOM.SITE.DP0.00016.001.02179.HOR.VER.000 | tempCellOut | Temperature (temp) of the optical cell (Cell) outlet (Out) thermocouple | 20Hz | real | celsius |
| irga | NEON.DOM.SITE.DP0.00016.001.01936.HOR.VER.000 | tempBloc | Temperature (temp) of the instrument block (Bloc) thermocouple | 20Hz | real | celsius |
| irga | NEON.DOM.SITE.DP0.00016.001.02180.HOR.VER.000 | presAtmBox | Pressure (pres), measured as atmospheric (Atm) pressure of the control box (Box), synonymous with absolute pressure or total pressure (at sea level the standard atmospheric pressure is 101.325 kPa) | 20Hz | real | kilopascal |
| irga | NEON.DOM.SITE.DP0.00016.001.02181.HOR.VER.000 | presGageCell | Pressure (pres), measured as differential against ambient pressure, synonymous with gage (Gage) pressure (at sea level the gage pressure equals total pressure minus 101.325 kPa), between the optical cell (Cell) and the control box | 20Hz | real | kilopascal |
| irga | NEON.DOM.SITE.DP0.00016.001.02182.HOR.VER.000 | pwrH2OSamp | Power (pwr) of the water vapor (H2O) signal in the absorption | 20Hz | real | watt |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------|---|------------|---|-------------------------------|------|-------------------------|--|
| | | | | band used for sampling (Samp) | | | |
| irga | NEON.DOM.SITE.DP0.00016.001.02183.HOR.VER.000 | pwrH2ORef | Power (pwr) of the water vapor (H2O) signal in the absorption band used for reference (Ref) | 20Hz | real | watt | |
| irga | NEON.DOM.SITE.DP0.00016.001.02184.HOR.VER.000 | asrpH2O | Electromagnetic absorptance (asrp) in the water vapor (H2O) absorption band | 20Hz | real | dimensionless | |
| irga | NEON.DOM.SITE.DP0.00016.001.02185.HOR.VER.000 | rhoMoleH2O | Density (rho) on molar basis (Mole) of water vapor (H2O), synonymous with number density | 20Hz | real | millimolesPerCubicMeter | |
| irga | NEON.DOM.SITE.DP0.00016.001.02186.HOR.VER.000 | fdMoleH2O | Dry mole fraction (fd) on molar basis (Mole) of water vapor (H2O), synonymous with mixing ratio | 20Hz | real | millimolesPerMole | |
| irga | NEON.DOM.SITE.DP0.00016.001.02187.HOR.VER.000 | pwrCO2Samp | Power (pwr) of the carbon dioxide (CO2) signal in the absorption band used for sampling (Samp) | 20Hz | real | watt | |
| irga | NEON.DOM.SITE.DP0.00016.001.02188.HOR.VER.000 | pwrCO2Ref | Power (pwr) of the carbon dioxide (CO2) signal in the absorption | 20Hz | real | watt | |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

| | | | | band used for reference (Ref) | | | |
|------|---|------------|--|-------------------------------|---------|-------------------------|--|
| irga | NEON.DOM.SITE.DP0.00016.001.02189.HOR.VER.000 | asrpCO2 | Electromagnetic absorptance (asrp) in the carbon dioxide (CO2) absorption band | 20Hz | real | dimensionless | |
| irga | NEON.DOM.SITE.DP0.00016.001.02190.HOR.VER.000 | rhoMoleCO2 | Density (rho) on molar basis (Mole) of carbon dioxide (CO2), synonymous with number density | 20Hz | real | millimolesPerCubicMeter | |
| irga | NEON.DOM.SITE.DP0.00016.001.02191.HOR.VER.000 | fdMoleCO2 | Dry mole fraction (fd) on molar basis (Mole) of carbon dioxide (CO2), synonymous with mixing ratio | 20Hz | real | micromolesPerMole | |
| irga | NEON.DOM.SITE.DP0.00016.001.01930.HOR.VER.000 | idx | Index value (idx) | 20Hz | integer | NA | |
| irga | NEON.DOM.SITE.DP0.00016.001.01931.HOR.VER.000 | diag | Diagnostic value (diag) | 20Hz | integer | NA | |
| irga | NEON.DOM.SITE.DP0.00016.001.02192.HOR.VER.000 | diag2 | Diagnostic value (diag) number 2 (2; sync clocks) | 20Hz | integer | NA | |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|------|---|-------------|--|------|------|------------|
| | irga | NEON.DOM.SITE.DP0.00016.001.02193.HOR.VER.000 | poteCool | Electric potential (pote) at the cooler (Cool) | 20Hz | real | volt |
| | irga | NEON.DOM.SITE.DP0.00016.001.02194.HOR.VER.000 | ssiCO2 | Signal strength indicator (ssi) for the carbon dioxide (CO2) absorption band | 20Hz | real | percent |
| | irga | NEON.DOM.SITE.DP0.00016.001.02195.HOR.VER.000 | ssiH2O | Signal strength indicator (ssi) for the water vapor (H2O) absorption band | 20Hz | real | percent |
| CD00380110 | irga | NEON.DOM.SITE.DP0.00016.001.02178.HOR.VER.000 | tempCellIn | Temperature (temp) of the optical cell (Cell) inlet (In) thermocouple | 20Hz | real | celsius |
| | irga | NEON.DOM.SITE.DP0.00016.001.02179.HOR.VER.000 | tempCellOut | Temperature (temp) of the optical cell (Cell) outlet (Out) thermocouple | 20Hz | real | celsius |
| | irga | NEON.DOM.SITE.DP0.00016.001.01936.HOR.VER.000 | tempBloc | Temperature (temp) of the instrument block (Bloc) thermocouple | 20Hz | real | celsius |
| | irga | NEON.DOM.SITE.DP0.00016.001.02180.HOR.VER.000 | presAtmBox | Pressure (pres), measured as atmospheric (Atm) pressure of the control box (Box), synonymous with absolute pressure or total pressure (at sea level the standard | 20Hz | real | kilopascal |



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| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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| | | | | atmospheric pressure is 101.325 kPa) | | | |
| irga | NEON.DOM.SITE.DP0.00016.001.02181.HOR.VER.000 | presGageCell | Pressure (pres), measured as differential against ambient pressure, synonymous with gage (Gage) pressure (at sea level the gage pressure equals total pressure minus 101.325 kPa), between the optical cell (Cell) and the control box | 20Hz | real | kilopascal | |
| irga | NEON.DOM.SITE.DP0.00016.001.02182.HOR.VER.000 | pwrH2OSamp | Power (pwr) of the water vapor (H2O) signal in the absorption band used for sampling (Samp) | 20Hz | real | watt | |
| irga | NEON.DOM.SITE.DP0.00016.001.02183.HOR.VER.000 | pwrH2ORef | Power (pwr) of the water vapor (H2O) signal in the absorption band used for reference (Ref) | 20Hz | real | watt | |
| irga | NEON.DOM.SITE.DP0.00016.001.02184.HOR.VER.000 | asrpH2O | Electromagnetic absorptance (asrp) in the water vapor (H2O) absorption band | 20Hz | real | dimensionless | |



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| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------|---|------------|---|------|------|-------------------------|
| irga | NEON.DOM.SITE.DP0.00016.001.02185.HOR.VER.000 | rhoMoleH2O | Density (rho) on molar basis (Mole) of water vapor (H2O), synonymous with number density | 20Hz | real | millimolesPerCubicMeter |
| irga | NEON.DOM.SITE.DP0.00016.001.02186.HOR.VER.000 | fdMoleH2O | Dry mole fraction (fd) on molar basis (Mole) of water vapor (H2O), synonymous with mixing ratio | 20Hz | real | millimolesPerMole |
| irga | NEON.DOM.SITE.DP0.00016.001.02187.HOR.VER.000 | pwrCO2Samp | Power (pwr) of the carbon dioxide (CO2) signal in the absorption band used for sampling (Samp) | 20Hz | real | watt |
| irga | NEON.DOM.SITE.DP0.00016.001.02188.HOR.VER.000 | pwrCO2Ref | Power (pwr) of the carbon dioxide (CO2) signal in the absorption band used for reference (Ref) | 20Hz | real | watt |
| irga | NEON.DOM.SITE.DP0.00016.001.02189.HOR.VER.000 | asrpCO2 | Electromagnetic absorptance (asrp) in the carbon dioxide (CO2) absorption band | 20Hz | real | dimensionless |
| irga | NEON.DOM.SITE.DP0.00016.001.02190.HOR.VER.000 | rhoMoleCO2 | Density (rho) on molar basis (Mole) of carbon dioxide (CO2), synonymous with number density | 20Hz | real | millimolesPerCubicMeter |



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| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|-------------|---|-----------|--|-------|---------|-------------------|
| | irga | NEON.DOM.SITE.DP0.00016.001.02191.HOR.VER.000 | fdMoleCO2 | Dry mole fraction (fd) on molar basis (Mole) of carbon dioxide (CO2), synonymous with mixing ratio | 20Hz | real | micromolesPerMole |
| | irga | NEON.DOM.SITE.DP0.00016.001.01930.HOR.VER.000 | idx | Index value (idx) | 20Hz | integer | NA |
| | irga | NEON.DOM.SITE.DP0.00016.001.01931.HOR.VER.000 | diag | Diagnostic value (diag) | 20Hz | integer | NA |
| | irga | NEON.DOM.SITE.DP0.00016.001.02192.HOR.VER.000 | diag2 | Diagnostic value (diag) number 2 (2; sync clocks) | 20Hz | integer | NA |
| | irga | NEON.DOM.SITE.DP0.00016.001.02193.HOR.VER.000 | poteCool | Electric potential (pote) at the cooler (Cool) | 20Hz | real | volt |
| | irga | NEON.DOM.SITE.DP0.00016.001.02194.HOR.VER.000 | ssiCO2 | Signal strength indicator (ssi) for the carbon dioxide (CO2) absorption band | 20Hz | real | percent |
| | irga | NEON.DOM.SITE.DP0.00016.001.02195.HOR.VER.000 | ssiH2O | Signal strength indicator (ssi) for the water vapor (H2O) absorption band | 20Hz | real | percent |
| CA11460000 | irgaMfcSamp | NEON.DOM.SITE.DP0.00012.001.01952.HOR.VER.000 | frtSet0 | Flow rate (frt) set point (Set) at National Institute of Standards and Technology | 20 Hz | real | litersPerMinute |



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| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|-----------|-------------|---|---------|--|-------|------|-----------------|
| | | | | standard conditions (0; temperature 293.15 K, pressure 101.325 kPa), synonymous with mass flow rate set point | | | |
| | irgaMfcSamp | NEON.DOM.SITE.DP0.00012.001.01951.HOR.VER.000 | frt0 | Flow rate (frt) at National Institute of Standards and Technology standard conditions (0; temperature 293.15 K, pressure 101.325 kPa), synonymous with mass flow rate | 20 Hz | real | litersPerMinute |
| | irgaMfcSamp | NEON.DOM.SITE.DP0.00012.001.01950.HOR.VER.000 | frt | Flow rate (frt) at site temperature and pressure, synonymous with volumetric flow rate | 20 Hz | real | litersPerMinute |
| | irgaMfcSamp | NEON.DOM.SITE.DP0.00012.001.01948.HOR.VER.000 | presAtm | Pressure (pres), measured as atmospheric (Atm) pressure, synonymous with absolute pressure or total pressure (at sea level the standard atmospheric pressure is 101.325 kPa) | 20 Hz | real | kilopascal |
| | irgaMfcSamp | NEON.DOM.SITE.DP0.00012.001.01949.HOR.VER.000 | temp | Temperature (temp) | 20 Hz | real | celsius |
| 034150000 | irgaMfcVali | NEON.DOM.SITE.DP0.00015.001.01952.HOR.VER.000 | frtSet0 | Flow rate (frt) set point (Set) at National Institute of Standards | 1 Hz | real | litersPerMinute |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|--|-------------|---|---------|--|------|------|-----------------|
| | | | | and Technology standard conditions (0; temperature 293.15 K, pressure 101.325 kPa), synonymous with mass flow rate set point | | | |
| | irgaMfcVali | NEON.DOM.SITE.DP0.00015.001.01951.HOR.VER.000 | frt0 | Flow rate (frt) at National Institute of Standards and Technology standard conditions (0; temperature 293.15 K, pressure 101.325 kPa), synonymous with mass flow rate | 1 Hz | real | litersPerMinute |
| | irgaMfcVali | NEON.DOM.SITE.DP0.00015.001.01950.HOR.VER.000 | frt | Flow rate (frt) at site temperature and pressure, synonymous with volumetric flow rate | 1 Hz | real | litersPerMinute |
| | irgaMfcVali | NEON.DOM.SITE.DP0.00015.001.01948.HOR.VER.000 | presAtm | Pressure (pres), measured as atmospheric (Atm) pressure, synonymous with absolute pressure or total pressure (at sea level the standard atmospheric pressure is 101.325 kPa) | 1 Hz | Real | kilopascal |
| | irgaMfcVali | NEON.DOM.SITE.DP0.00015.001.01949.HOR.VER.000 | temp | Temperature (temp) | 1 Hz | Real | celsius |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|---------------------|---|-----------|---|--------|---------|----|
| CD06450000 | irgaSndLeakHe at | NEON.DOM.SITE.DP0.00008.001.02197.HOR.VER.000 | qfTrapIn | Qualifying flag (qf) indicating the status of the water trap (Trap) inlet (In) solenoid (0 = open [default], 1 = close) | 0.2 Hz | integer | NA |
| | irgaSndLeakHe at | NEON.DOM.SITE.DP0.00008.001.02198.HOR.VER.000 | qfTrapOut | Qualifying flag (qf) indicating the status of the water trap (Trap) vent (Out) solenoid (0 = close [default], 1 = open) | 0.2 Hz | Integer | NA |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|--|-----------------|---|------------|---|--------|---------|----|
| | irgaSndLeakHeat | NEON.DOM.SITE.DP0.00008.001.02199.HOR.VER.000 | qfLeak | Qualifying flag (qf) indicating the status of the sampling line leak (Leak) test master solenoid (0 = leak test not being performed [default], 1 = leak test being performed) | 0.2 Hz | Integer | NA |
| | irgaSndLeakHeat | NEON.DOM.SITE.DP0.00008.001.02221.HOR.VER.000 | qfHeatSoni | Qualifying flag (qf) indicating the status of the heater (Heat; heated 3-D sonic (Soni) anemometer only; 0 = off [default], 1 = on) | 0.2 Hz | Integer | NA |



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| <i>Title:</i> NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | <i>Date:</i> 12/17/2019 |
| <i>NEON Doc. #:</i> NEON.DOC.000456 | <i>Author:</i> D. Durden, S. Metzger, J. Taylor, H. Loescher | <i>Revision:</i> E |

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|--|-----------------|---|------------|---|--------|---------|----|
| | irgaSndLeakHeat | NEON.DOM.SITE.DP0.00008.001.02222.HOR.VER.000 | qfHeatTube | Qualifying flag (qf) indicating the status of the heater (Heat) for the intake tube (Tube; 0 = heater on [default], 1 = heater off) | 0.2 Hz | Integer | NA |
| | irgaSndLeakHeat | NEON.DOM.SITE.DP0.00008.001.02223.HOR.VER.000 | qfHeatCap | Qualifying flag (qf) indicating the status of the heater (Heat) for the rain cap (Cap; 0 = heater off [default], 1 = heater on) | 0.2 Hz | Integer | NA |



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| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|--------------------|---|------------|---|--------|---------|------------|
| | irgaSndLeakHeat | NEON.DOM.SITE.DP0.00008.001.02224.HOR.VER.000 | qfHeatVali | Qualifying flag (qf) indicating the status of the heater (Heat) for the validation gas (Vali) path (0 = heater off [default], 1 = heater on) | 0.2 Hz | integer | NA |
| CA07190000 | irgaPresTrap | NEON.DOM.SITE.DP0.00036.001.01948.HOR.VER.000 | presAtm | Pressure (pres), measured as atmospheric (Atm) pressure, synonymous with absolute pressure or total pressure (at sea level the standard atmospheric pressure is 101.325 kPa) | 1 Hz | real | kilopascal |
| CA07160000 | irgaPresValiLine | NEON.DOM.SITE.DP0.00037.001.02196.HOR.VER.000 | presGage | Pressure (pres), measured as differential against ambient pressure, synonymous with gage (Gage) pressure (at sea level the gage pressure equals total pressure minus 101.325 kPa) | 1 Hz | real | kilopascal |
| CA07160000 | irgaPresValiRegOut | NEON.DOM.SITE.DP0.00035.001.02196.HOR.VER.000 | presGage | Pressure (pres), measured as differential against ambient pressure, synonymous with gage (Gage) pressure (at sea | 1 Hz | real | kilopascal |



| | | | | | | | |
|---------------------------|-------------------|---|-------------|---|--------|---------|------------|
| | | | | level the gage pressure equals total pressure minus 101.325 kPa) | | | |
| CA07170000 | irgaPresValiRegln | NEON.DOM.SITE.DP0.00034.001.02196.HOR.VER.000 | presGage | Pressure (pres), measured as differential against ambient pressure, synonymous with gage (Gage) pressure (at sea level the gage pressure equals total pressure minus 101.325 kPa) | 1 Hz | real | kilopascal |
| CD07150000 and CD07150010 | irgaPump | NEON.DOM.SITE.DP0.00116.001.02351.HOR.VER.000 | pumpVoltage | Voltage provided to pump | 0.2 Hz | real | volt |
| CD06640003 | irgaSndValiHut | NEON.DOM.SITE.DP0.00011.001.02212.HOR.VER.000 | qfGas1 | Qualifying flag (qf) indicating validation gas (Gas) number 1 solenoid status (1; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiHut | NEON.DOM.SITE.DP0.00011.001.02213.HOR.VER.000 | qfGas2 | Qualifying flag (qf) indicating validation gas (Gas) number 2 solenoid status (2; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiHut | NEON.DOM.SITE.DP0.00011.001.02214.HOR.VER.000 | qfGas3 | Qualifying flag (qf) indicating validation gas (Gas) number 3 solenoid status (3; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |



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|------------|-----------------|---|--------|--|--------|---------|----|
| | irgaSndValiHut | NEON.DOM.SITE.DP0.00011.001.02215.HOR.VER.000 | qfGas4 | Qualifying flag (qf) indicating validation gas (Gas) number 4 solenoid status (4; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiHut | NEON.DOM.SITE.DP0.00011.001.02216.HOR.VER.000 | qfGas5 | Qualifying flag (qf) indicating validation gas (Gas) number 5 solenoid status (5; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| CD06640004 | irgaSndValiNema | NEON.DOM.SITE.DP0.00009.001.02212.HOR.VER.000 | qfGas1 | Qualifying flag (qf) indicating validation gas (Gas) number 1 solenoid status (1; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiNema | NEON.DOM.SITE.DP0.00009.001.02213.HOR.VER.000 | qfGas2 | Qualifying flag (qf) indicating validation gas (Gas) number 2 solenoid status (2; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiNema | NEON.DOM.SITE.DP0.00009.001.02214.HOR.VER.000 | qfGas3 | Qualifying flag (qf) indicating validation gas (Gas) number 3 solenoid status (3; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| | irgaSndValiNema | NEON.DOM.SITE.DP0.00009.001.02215.HOR.VER.000 | qfGas4 | Qualifying flag (qf) indicating validation gas (Gas) number 4 solenoid status (4; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |



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|---|---|------------------|
| Title: NEON Command, Control, and Configuration: Eddy-covariance Turbulent Exchange Subsystem | | Date: 12/17/2019 |
| NEON Doc. #: NEON.DOC.000456 | Author: D. Durden, S. Metzger, J. Taylor, H. Loescher | Revision: E |

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|------------|-----------------|---|-------------|--|--------|---------|-------------------|
| | irgaSndValiNema | NEON.DOM.SITE.DP0.00009.001.02216.HOR.VER.000 | qfGas5 | Qualifying flag (qf) indicating validation gas (Gas) number 5 solenoid status (5; 0 = close [default], 1 = open) | 0.2 Hz | integer | NA |
| 0353710000 | irgaGasCyl | NEON.DOM.SITE.DP0.00117.001.02191.HOR.VER.000 | fdMoleCO2 | Dry mole fraction (fd) on molar basis (Mole) of carbon dioxide (CO2), synonymous with mixing ratio | | real | micromolesPerMole |
| | irgaGasCyl | NEON.DOM.SITE.DP0.00117.001.02324.HOR.VER.000 | d13CO2 | Measure of the ratio of stable isotopes 13C:12C in CO2, relative to the Vienna Pee Dee Belemnite | | real | permill |
| | irgaGasCyl | NEON.DOM.SITE.DP0.00117.001.02318.HOR.VER.000 | fdMole12CO2 | Dry molar fraction (fd) of 12CO2 in the air | | real | micromolesPerMole |
| | irgaGasCyl | NEON.DOM.SITE.DP0.00117.001.02320.HOR.VER.000 | fdMole13CO2 | Dry molar fraction (fd) of 13CO2 in the air | | real | micromolesPerMole |

9.2 Validation and verification Tests – attitude and motion reference system

Aside from the default operation, the Xsens MTi-300-AHRS attitude and motion reference system (Sect. 4) shall also be used for validation and verification tests on a case-by-case basis. Such tests are relevant to (i) assess the influence of boom motions on the wind measurement (Sect. 3), and (ii) detect vibrations within the sensitive frequency range (140–160 Hz) of the H₂O, CO₂ concentration measurement (Sect. 4). For this purpose it shall be possible to operate the MTi-300-AHRS with a data acquisition frequency of 400 Hz. Table 22 specifies the configuration settings of the MTi-300-AHRS during validation and verification test.

Table 22. Validation and verification configuration settings for the Xsens MTi-300-AHRS.

| Parameter | Setting |
|------------------------------------|---|
| Sensor/Body coordinate system | forward-left-up (sensor-default) |
| Sensor/Reference coordinate system | east-north-up (ENU, sensor default) |
| Sensor/Misalignment | no misalignment |
| Sensor/GPS lever arm | no displacement |
| Heading reference | - |
| Motion profile | low mag_dep |
| Data Output/Status | status word |
| Data Output/Inertial Data | rate of turn, acceleration, free acceleration |
| Data Output/Orientation | Euler Angles |
| output frequency | 400 Hz |
| output configuration | trigger |
| Protocol | MTI low-level |
| serial communication | RS-232 |
| Baudrate | 115200 |
| data bits | 8 |
| Parity | none |
| stop bits | 1 |
| flow control | disabled |
| Captured LO DPs | Table 5 |

9.3 Problem tracking and resolution

The sensor command, control and configuration provides logic that can help identify problems in the ECTE system. This will be used to generate problem tickets in the problem tracking and resolution (PTR) system to have these field issues resolved by FOPS tower technicians. Additionally, these identified issues often

result in missing or bad data until the identified issue is resolved. These issues will be logged so that the data that is received may be properly flagged during CI processing at NEON HQ. The flagging process is performed manually using the Science Review flag; however, the information from PTR is extremely important to provide full QAQC of reported data products.

9.4 Assembly schematic drawing

See schematics in above sections for each part of the full assembly.

9.5 Acronyms

| Acronym | Description |
|----------------|--|
| 3-D | Three-dimensional |
| ATBD | Algorithm theoretical basis document |
| C ³ | Command, control, and configuration document |
| CVAL | NEON calibration, validation, and audit laboratory |
| DAS | Data acquisition system |
| DGD | Data generating device |
| DP | Data product |
| EC-TES | Eddy-covariance turbulent exchange subsystem |
| ENG | Engineering (NEON project team) |
| FIU | Fundamental instrument unit (NEON project team) |
| HQ | Headquarters |
| ID | Identification |
| L0–L4 | Level 0 through level 4 data products |
| NA | Not available/not applicable |
| NTP | Network Time Protocol |
| PDU | Power distribution unit |
| PN | Part number |
| PT | Project team |
| PTR | Problem tracking and resolution |
| QA/QC | Quality Assurance/Quality Control |
| SONIC | Ultrasonic anemometer/thermometer |
| SOP | Standard operations procedure |
| TBD | To be determined |
| TIS | Terrestrial Instrument System |

9.6 Functions

| Function | Description |
|-----------|--|
| d | Differential |
| max | Maximum |
| min | Minimum |
| \bar{X} | Short-term (e.g., 30 min) arithmetic mean of atmospheric quantity <i>X</i> |

9.7 Parameters

| Parameter | Description | Numeric value | Units |
|------------|---------------------------|---------------|-------|
| T_{zero} | Absolute zero temperature | -273.15 | °C |

9.8 Subscripts

| Subscript | Description |
|-----------|--------------------------------------|
| 1...N | Numeric identifier |
| air | Air (sum of dry air and water vapor) |
| drain | Water drain |
| IRGA | Infrared gas analyzer |
| m | Measurement |
| max | Maximum |
| min | Minimum |
| trap | Water trap |

9.9 Variables

| Variable | Description | Units |
|-----------------|--------------------------------|--------------------------------|
| acc | Boom arm acceleration | $m\ s^{-2}$ |
| b | Individual bit of binary data | Dimensionless (0 or 1) |
| c | Speed of sound in air | $m\ s^{-1}$ |
| dp_{IRGA} | IRGA pressure drop | kPa |
| α, β | Pitch and roll rotation angles | Decimal degree |
| θ | Sonic anemometer pitch | Decimal degree |
| i | Running index | Dimensionless (count) |
| p | Pressure | $Pa \equiv kg\ m^{-1}\ s^{-2}$ |
| t | Time | s |
| T | Absolute temperature | K |
| T_{H2O} | Dew point temperature | K |

| Variable | Description | Units |
|-----------|---|---|
| u, v, w | Along-, cross- and vertical wind speed | m s^{-1} |
| ϕ | Sonic anemometer roll | Decimal degree |
| x, y, z | Along-, cross- and vertical axes of a Cartesian coordinate system | Dimensionless |
| X, Y | Placeholder for atmospheric quantities | Depending on unit of atmospheric quantity |
| Ψ | Wind direction | Decimal degree |
| Ψ_0 | Wind direction offset | Decimal degree |

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