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CO/H_2/N_2O Analyzer Instrument Handbook

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Revised April 2025

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
AMF	ARM Mobile Facility
AMF1	first ARM Mobile Facility
AMF2	second ARM Mobile Facility
AMF3	third ARM Mobile Facility
AOS	Aerosol Observing System
ARM	Atmospheric Radiation Measurement
CO	carbon monoxide
ENA	East North Atlantic
GUI	graphical user interface
H_2O	water
ICOS	integrated cavity output spectroscopy
LBNL	Lawrence Berkeley National Laboratory
LGR	Los Gatos Research
MAOS	Mobile Aerosol Observing System (an intensively instrumented AOS)
MFC	mass flow controller
NIST	National Institute of Standards and Technology
N_2O	nitrous oxide
PFA	perfluoroalkoxy alkane
QC	quality control
SGP	ARM Southern Great Plains site

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Carbon monoxide/water vapor/nitrous oxide ($CO/H_2O/N_2O$) analyzer

2.0 Mentor Contact Information

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Instrument manual available from manufacturer http://www.lgrinc.com

4.0 Instrument Description

Los Gatos Research (LGR) $CO/H_2O/N_2O$ analyzer instruments are deployed in the ARM Aerial Facility (AAF), ARM Mobile Facility 1 (AMF1), ARM Mobile Facility 2 (AMF2), ARM Mobile Facility 3 (AMF3), and Aerosol Observing System (AOS), East North Atlantic (ENA; site of a permanent AOS).

Figure 1 and Figure 2 are images of Model 907-0015 (deployed in the AAF, AMF1, AMF3, and ENA) and Model 098-0014 (deployed in AMF2). Both images are from the instrument manuals published by LGR.

Figure 1. Model 907-0015 (AAF, AMF1, AMF3, ENA) (from LGR manual).

Figure 2. Model 098-0014 (AMF2) (from LGR manual).

These instruments are functionally identical except for a fast-flow capability on the AAF instrument.

The N_2O/CO analyzer uses LGR's patented off-axis integrated cavity output spectroscopy **(**ICOS) technology, which employs a high-finesse optical cavity as the measurement cell. LGR's technology has many advantages over conventional first-generation cavity ring-down spectroscopy techniques. In brief, because the laser beam does not have to be resonantly coupled to the measurement cell, precise beam alignment is not critical. Mentors can disassemble the cell to carefully clean the front surface mirrors. The analyzers are relatively inexpensive and inherently robust thermally and mechanically. In addition, because the LGR technology can record reliable absorption spectra over a far wider range of optical depths (absorbance values) than first-generation cavity ring-down spectroscopy, LGR analyzers provide measurements over a much wider range of mixing ratios (gas concentrations). The N_2O/CO analyzer includes an internal computer that sends real-time data to the local instrument computer through its digital (RS-232) output.

Instruments can be communicated directly through an Ethernet connection, but the current Linux operating system that has been installed does not support modern updates and poses a security risk.

The internal flow scheme for the instrument is shown in Figure 3.

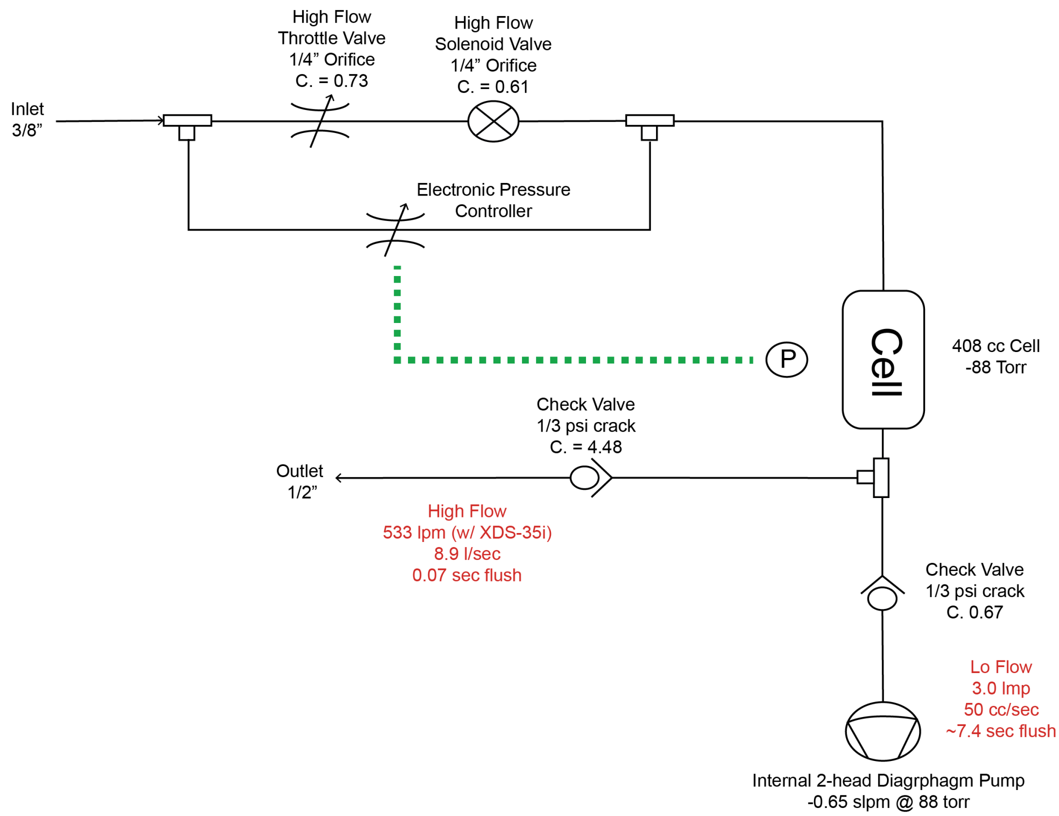

Figure 3. Internal flow schematic (from LGR manual).

The “High Flow” option is available only on the aircraft unit but has not been used to date.

Modifications for ground measurements include:

- Addition of a 47-mm × 5-µm Teflon filter on the inlet line.
- Standard addition calibrations on a daily basis. Calibrations have varied by installation.
  - AAF. Originally a displacement calibration was performed every 30-m in parallel with the Picarro CO_2/CH_4 instrument. Currently (beginning in ACME V), calibrations will be done by post-program comparison with canister samples analyzed for CO and NO_2. A separate standalone calibration system similar to ENA is planned for the future.
  - AMF3. A mixed gas standard is shared with the Greenhouse Gas Analyzer (Picarro CO_2/CH_4 instrument). On a daily basis, a ~10-20 sccm standard addition is introduced into the instrument flow. On a weekly basis, a 1 SLPM replacement calibration is done with the same standard.
  - ENA. The Greenhouse Gas Analyzer (Picarro CO2/CH4 instrument) shares a mixed gas standard. On a daily basis, a ~10 to 20 sccm standard addition is introduced into the instrument flow. On a weekly basis, a 1 SLPM replacement calibration is done with the same standard.

– MAOS-C. A 2X daily standard addition is done by introducing ~40 sccm of ~100 ppmv CO standard into the fast-flow trace gas manifold. No effort is made to standardize the ancillary measurements of H_2O and N_2O. This calibration system is scheduled as an upgrade to the system used in ENA.

5.0 Measurements Taken

The primary measurement output from the LGR CO Analyzer is the concentration of the three analytes (CO, H_2O, and N_2O) reported at 1-second resolution in units of parts per billion by volume (ppbv) in ambient air. Accompanying instrument outputs include sample and ambient temperatures and chamber pressure. Ancillary information from a custom calibration system is appended at the end of each record, as is a field for operator comments.

6.0 Links to Definitions and Relevant Information

6.1 Data Object Description

6.1.1 Raw Data

The "raw" instrument datastream outputs include all parameters measured by the instrument. Metadata are included automatically in each hourly file.

The metadata are identified in the following list:

Row 1:	Filename
Row 4 (column 1 only)	ARM Climate Research Facility
Row 5:	SitePlatform
Row 7:	Last revised date
Row 9:	Instrument
Row 10:	Instrument Serial Number/ARM Inventory Number (WD#)
Row 13:	Instrument Mentor/Affiliation
Rows 14-19:	Comments (operational conditions, calibrations, etc.)
Rows 21-24:	Constants (usually defined in Comments)
Row 35:	Column title
Row 36:	Column units line 1
Row 37:	Column units line 2
Row 40:	First row of data

Data fields in the raw output begin on Row 40 and are listed below:

Date Time	Primary Date/Time stamp yyyy-mm-dd hh:mm:ss as set by the instrument computer and referenced to the site Network Time Protocol server (or if unavailable, linked to the master computer in the AOS)
Inst. Time	Time set on the internal computer. This should be equal to the primary Date/Time, but can vary if the operator has not set the instrument time. This value is usually discarded.
CO	Mixing ratio of carbon monoxide in ambient air (ppmv)
CO_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
N2O	Mixing ratio of nitrous oxide in ambient air (ppmv)
N2O_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
H2O	Mixing ratio of water vapor in ambient air (ppmv)
H2O_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
Co_dry	Mixing ratio of carbon monoxide corrected for the (measured) water vapor concentration measured at the same time (ppmv)
CO_dry_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
N2O_dry	Mixing ratio of nitrous oxide corrected for the (measured) water vapor concentration measured at the same time (ppmv)
N2O_dry_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
GasP	Gas pressure in the sample cell (torr)
GasP_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
GasT	Gas temperature in the sample cell (C)
GasT_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
AmbT	Temperature of the instrument interior (C)

AmbT_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.

The channels above are standard for all instruments. LGR has modified the outputs of subsequent models of this instrument. This has complicated documentation and made standardization impossible.

Gnd	Unused
Gnd_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
LTCO	Unused
LTCO_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
AIN5	Unused
AIN5_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
AIN6	Unused
AIN6_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
AIN7	Unused
AIN7_se	Standard error. This is the standard deviation of the previous measurement over the averaging period. Because instrument data are recorded at the instrument frequency (1 second), this error is 0.
FitFlag	Used internally for processing.

Beginning with ENA deployment in April 2015, a new calibration system was implemented. As of July 31, 2015, the new system is operational in ENA. It will gradually be expanded to the other installations. The new data files now include the following additional fields:

1. Valve 1 position. Valve 1 is a 0-20 sccm Mass Flow Controller (MFC) set to deliver a standard addition to the sample flow. A string field with either ‘open’, ‘closed’ or ‘error’. If’ closed’ or ‘error’, there is no flow of gas. If ‘open’, the gas flow should be taken from the field ‘Flow 1 read’.
2. Flow 1 setpoint. The setpoint for the first MFC. This should not change.
3. Flow 1 read. This is the actual readout of the MFC. It is uncalibrated. The true flow is taken from a + Flow 1 read * b where a,b are the intercept and slope of the MFC calibration (provided in a configuration file along with date of calibration).

4. Valve 2 position. Valve 2 is a 0-2.0 SLPM MFC set to deliver a replacement calibration to the sample flow. A string field with either ‘open’, ‘closed’ or ‘error’. If’ closed’ or ‘error’, there is no flow of gas. If ‘open’, the gas flow should be taken from the field ‘Flow 1 read’.
5. Flow 2 setpoint. The setpoint for the second MFC. This should not change.
6. Flow 2 read. This is the actual readout of the MFC. It is uncalibrated. The true flow is taken from a + Flow 1 read * b where a,b are the intercept and slope of the MFC calibration (provided in a configuration file along with date of calibration). However, since the flow exceeds the instrument inlet flow (i.e., displacement calibration), the exact flow is immaterial.
7. Comment. This field is the last field in the data stream. It allows operators to enter free-form text from the graphical user interface (GUI) at any time. Operational notes or disruptions may be entered here.

These data are saved unaltered as produced by the instrument. Processing of raw data must be able to deal with more than one record per second and time periods with either no data or only a date/time stamp in the record. If the instrument does not put out a number, the instrument computer can include a record of empty fields. Because neither the instrument clock nor the instrument computer clock are perfect, minor irregularities (called dithering) in the output datastream can occur.

6.1.2 Processed Datastream

In general, the “raw” data are processed by ARM. The processed data files include information such as the site of the measurement (usually the three-letter specifier of the nearest airport), platform (the structure used for the instrument (aos | aaf), subsite (m1 : main site | s1 : supplemental site), species measured (CO, N_2O. H_2O), and processing level (a1 or b1). Data is processed as the mixing volume of the species (CO, N_2O. H_2O) in ambient air with and without water vapor correction. For example, for the CO species, the data is given as ‘co’ and ‘co_dry,’ respectively.

At the "a" level of processing, data are typically ingested hourly and added to output NetCDF files. These files are then split daily at midnight UTC. Data quality officers (DQO) perform the first quality control (QC), which includes comparison, persistence, standard deviation, and flow rate tests. At the "b" level, a1-level data undergoes further processing. This involves applying advanced instrument calibration data and correction factors provided by mentors or documented in the literature. The calibration, correction, and QC limit information are all documented in the output NetCDF files. It's important to note that no standard additions or displacement calibrations are removed from the data streams, and users should be aware of this when utilizing the data for analysis. MFC_1 and MFC_2 indicate when a standard addition or displacement calibration occurs.

Time is reported as Coordinated Universal Time (UTC) as set by a Network Time Protocol server. Following convention, the time is the beginning of the period. The parameter reported at this time is the average of all points less than or equal to the time and less than the next time. Data are reported at 1-second resolution. All non-operational periods have been removed (empty field or NAN).

6.2 Data Ordering

$CO/H_2O/N_2O$ data collected are distributed through the ARM Data Discovery or can be ordered from https://www.arm.gov/capabilities/instruments/co-analyzer. Data are organized by campaign or site.

6.3 Data Plots

Figure 4 through Figure 8 are examples of plots generated from data collected by the $CO/H_2O/N_2O$ monitor.

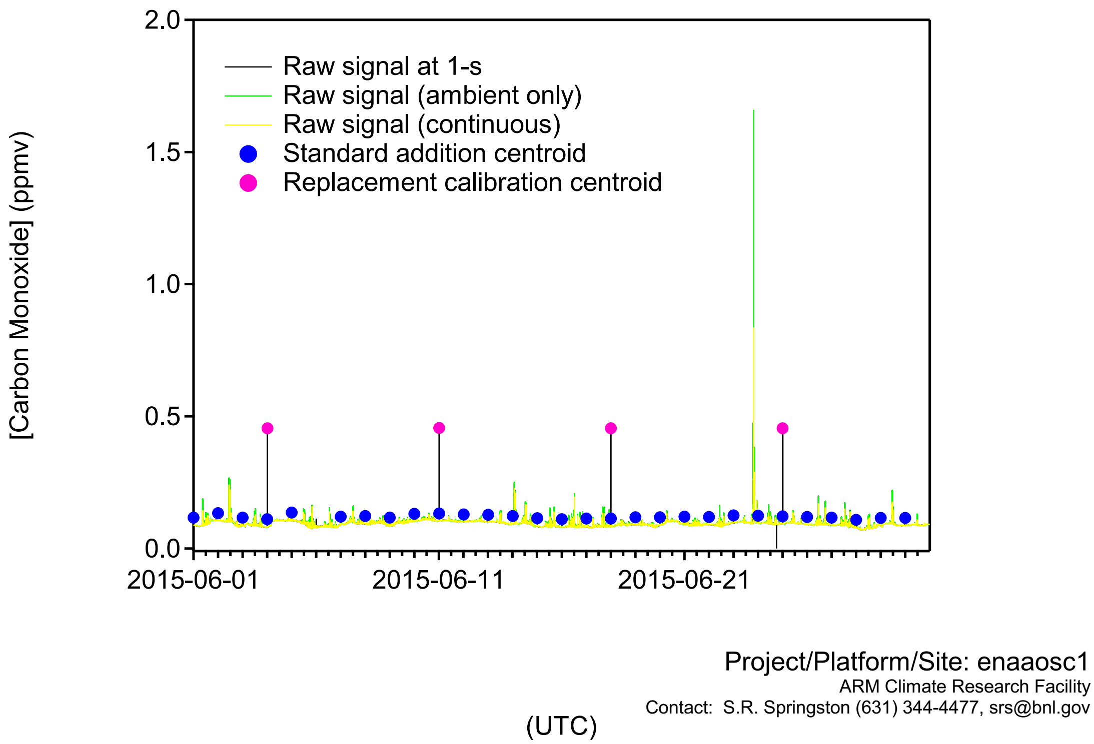

Figure 4. Raw CO data collected by an LGR ICOS CO, H_2O, N_2O analyzer for 1 month in June 2015.

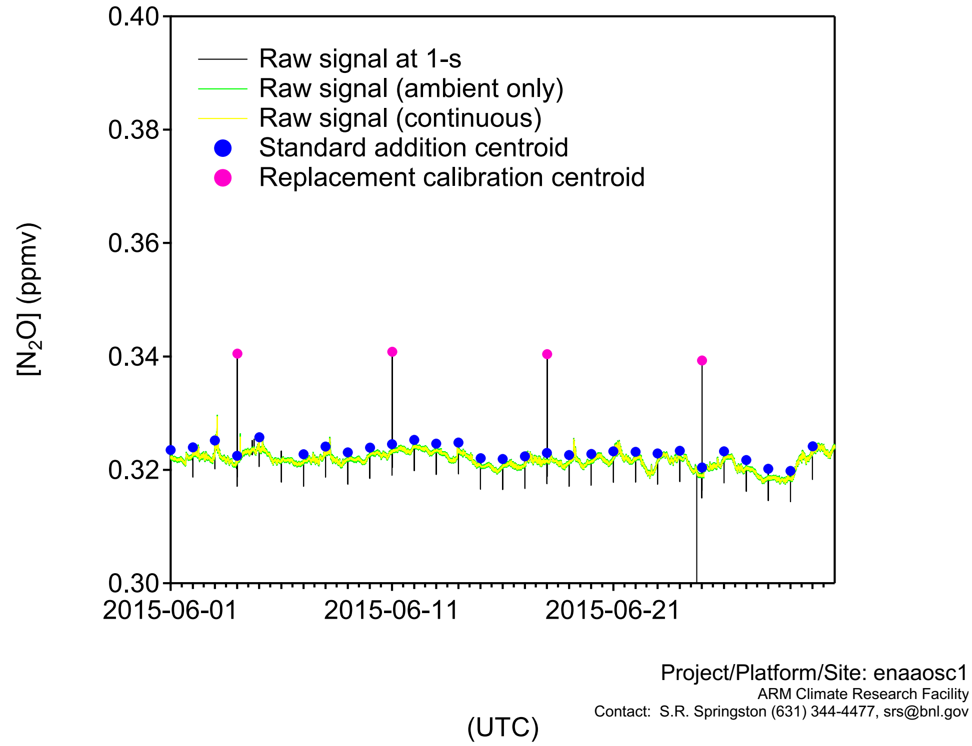

Figure 5. Raw N_2O data collected by an LGR ICOS CO, H_2O, N_2O analyzer for 1 month in June 2015.

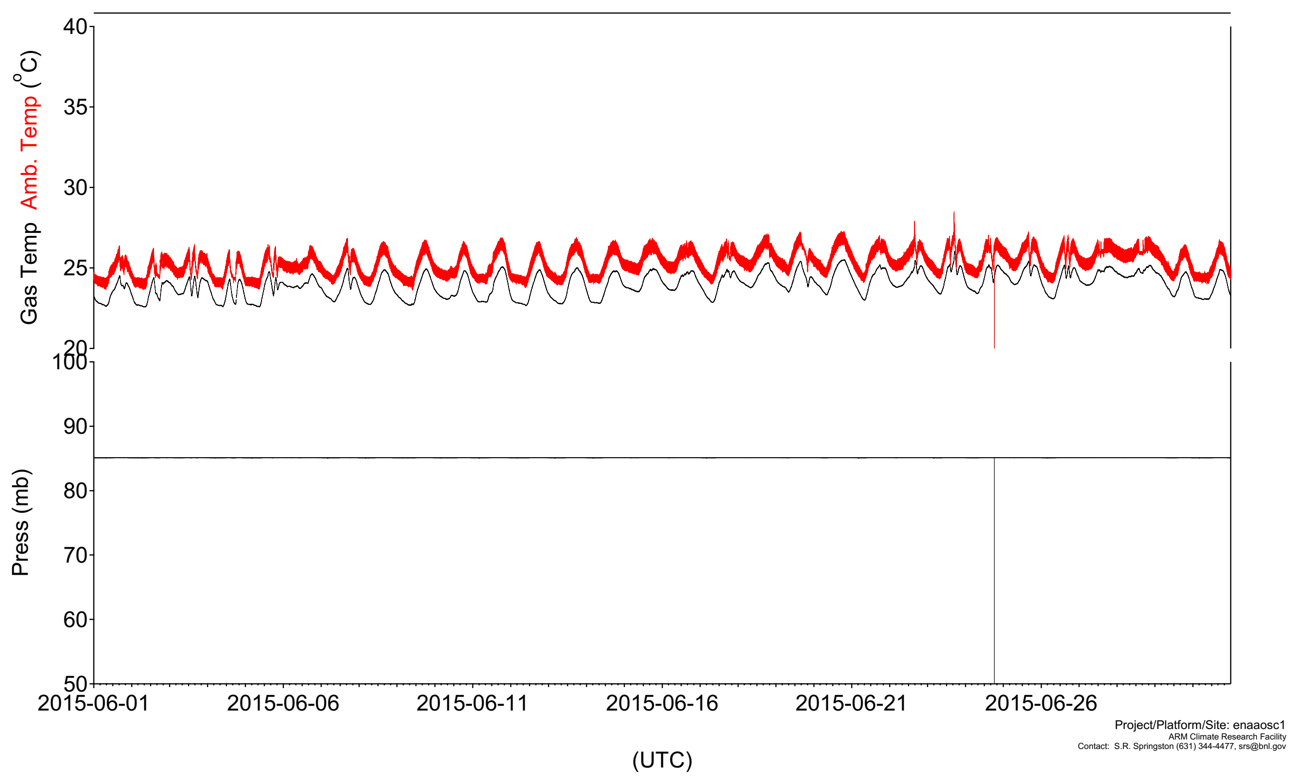

Figure 6. Housekeeping data from LGR ICOS CO/H_2O/N_2O analyzer for 1 month in June 2015.

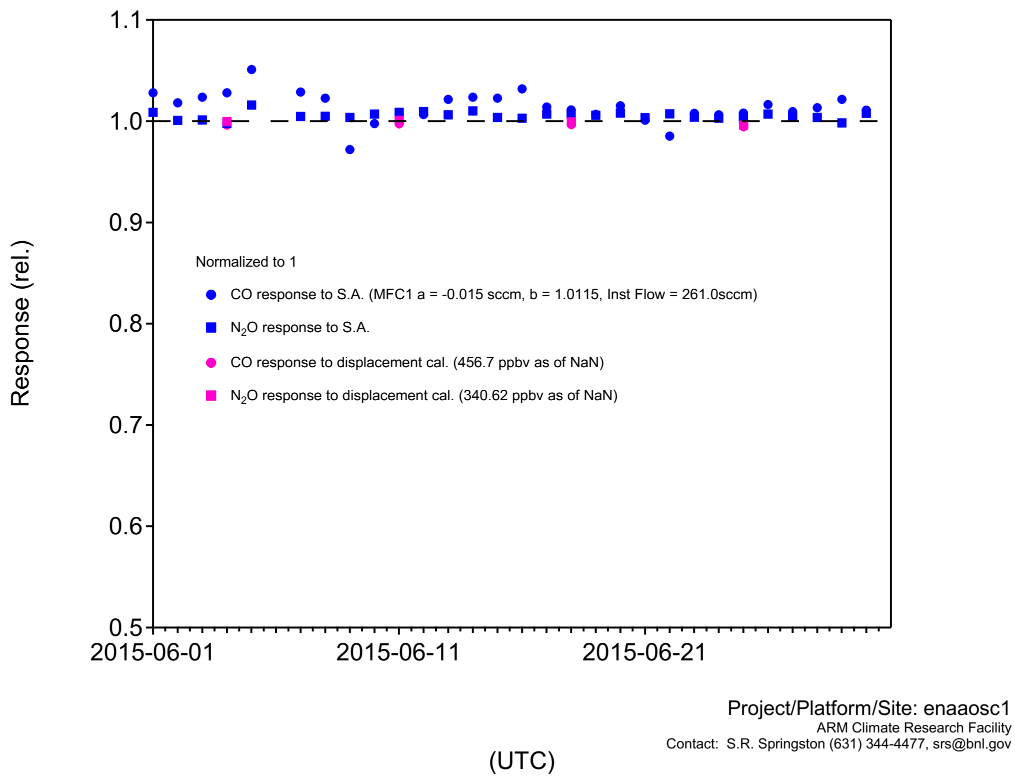

Figure 7. Calibration results from LGR ICOS $CO/H_2O/N_2O$ analyzer for 1 month in June 2015.

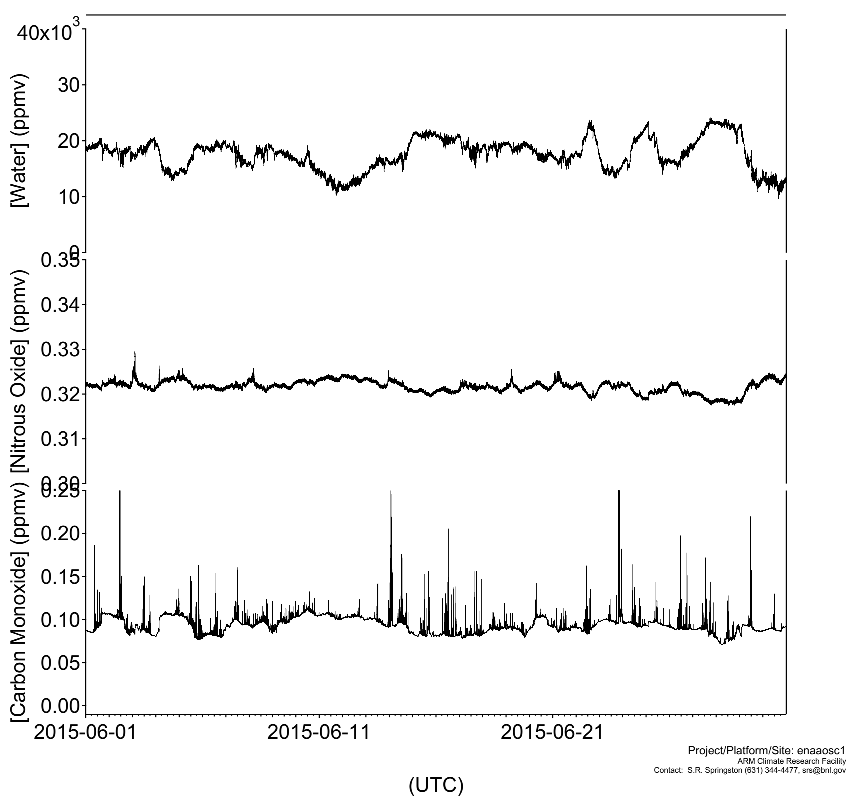

Figure 8. Processed data from LGR ICOS $CO/H_2O/N_2O$ analyzer for 1 month in June 2015.

6.4 Data Quality

The first level of data quality is the automatic flagging of data when chamber pressure deviates >5 mb from nominal.

The second level of data quality is an inspection of the daily standard addition and weekly replacement gas calibrations. The latest calibrated instrument flow rates and standard MFC flow rates are used to calculate the standard addition response. These are nominally within ~10% of the expected value. Deviations from 1 can be explained by gradual drift of instrument flow rate or MFC calibrations. The weekly replacement gas calibration is more precise because the signal is larger and it is independent of instrument and MFC flow rates. These are usually within 1% to 2% of nominal calibrations.

Comparison of the AAF CO instrument with flask samples analyzed post-program indicate an accuracy for CO and N_2O of better than 5% of nominal. It should be noted that the nominal response on this instrument has been questioned as being 5% off. Thus, the final accuracy of the aircraft instrument is judged to be within 1 to 2% (worst case).

6.5 Calibration Database

The ground-based LGR $CO/H_2O/N_2O$ analyzers are calibrated for response daily by either standard addition or replacement calibration. These results are collected by the mentor. The flow rates of the instrument and the MFCs are calibrated prior to a campaign and on a 6-month to 1-year schedule, depending on unit accessibility. Fluctuations are on the order of ~1%. Flows are measured either by a Gilibrator (calibrated against a primary standard soap-bubble flow meter) or a Defender Dry Gas Calibrator (calibrated annually against a primary standard soap-bubble flow meter at Brookhaven National Laboratory). The gaseous standards for CO are either National Institute of Standards and Technology (NIST)-traceable, commercial standards, or a shared CO/N_2O standard provided by Sebastien Biraud of Lawrence Berkeley National Laboratory (LBNL).

Because water vapor is not a primary measurement reported by this instrument, it is not regularly calibrated against a water vapor standard. However, laboratory tests of this model against a dew-point hygrometer have shown excellent correspondence.

Zero checks are not performed. Depending on the manufacturer's tuning, the instrument will not operate below ~30 to 40 ppbv CO. This is because the unit must lock the Quantum Cascade Laser on an active absorbance line of the CO spectra. The manufacturer considers this to be a "first principles" measurement for the zero point. Laboratory tests with scrubbed zero air have shown a y-intercept to be within ±0.2 to 0.3 ppbv for CO.

7.0 Technical Specification

7.1 Units

The measured quantity of interest is the mixing volume of the analyte. This is reported in units of parts per million by the instrument. The instrument also reports CO and N_2O in dry air using the measured H_2O

concentration. Generally, the dry air concentration is not reported because it includes the combined imprecision of both the analyte and water measurements.

7.2 Range

The full range of this model is somewhat arbitrary. Ambient CO never goes below ~50 to 60 ppbv because of global backgrounds. Laboratory tests by the mentor have shown excellent linearity (better than 0.5%) to 5 ppm and above. Ambient N_2O varies very little in the troposphere. Linearity and range are not an issue. Properly tuned by the manufacturer, the instrument can measure water vapor (non-condensing) from approximately <2000 to 5000 ppm to saturated.

7.3 Accuracy

Calibrated at 1-day intervals with standard addition and 7-day intervals with replacement addition using a high-precision standard (<1%), the total accuracy for CO and N_2O is ±2 ppbv or ±2%, whichever is greater. Under ideal circumstances (recent flow calibrations and high-quality standards), evidence points to better accuracy, approaching ±1% for both gases.

7.4 Repeatability

Precision (repeatability) is given here as the noise of the 1-second signal. Under quiet ambient conditions, this is:

[CO] σ = 0.05 ppbv

[H_2O] σ = 150 ppmv

[N_2O] σ = 0.08 ppbv

Therefore, for normally distributed noise, ±2σ encompasses 95% of the points. The precision of the instrument under average ambient conditions is then given as:

[CO] 95% confidence interval = ± 0.1 ppbv

[H_2O] 95% confidence interval = ± 300 ppmv

[N_2O] 95% confidence interval = ± 0.2 ppbv

Note that these confidence intervals represent repeatability over a relatively short period. Day-to-day and month-to-month repeatability has a larger confidence interval and approaches the accuracy uncertainties given in the previous section.

7.5 Sensitivity

Sensitivity is not meaningful for CO and N_2O because background tropospheric concentrations are well above the minimum detectable limit of the unit. For water vapor, the instrument can “bottom out” under arctic dry conditions (below ~500 ppmv).

7.6 Uncertainty

Uncertainty is an integral of all errors. It is a combined measurement of accuracy and precision (repeatability) discussed above. If a systematic bias to a standard is noted during individual calibrations, the mentor should be contacted.

7.7 Output Values

Output values are described in Section 6.0.

8.0 Instrument System Functional Diagram

A functional diagram of the optical cell is shown in Figure 9.

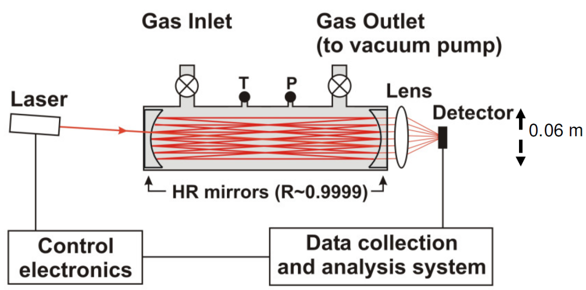

Figure 9. Functional diagram of optical cell.

As of August 3, 2015, there are two calibration configurations. In MAOS-C, a standard addition to the hi-flow perfluoroalkoxy alkane (PFA) inlet is used. This depends on knowing the flow through the inlet as measured by a rotometer. Although the inlet manifold flow is measured, the accuracy of this calibration is uncertain to ±5 to 10%. A schematic of the inlet for the ground-based unit is shown in Figure 10.

In newer installations (AMF3, ENA, and the ARM Southern Great Plains [SGP] site), a dual MFC system is used to add sample to the much lower instrument inlet flow. A standard addition is performed once per day using ~20 sccm of calibration gas. This depends on knowing the MFC flow *AND* the instrument flow as calibrated during mentor visits. On a weekly basis a displacement flow calibration is done by using the second MFC at a rate higher than the instrument flow. This calibration is independent of flow calibrations and gives a primary reading, though it cannot account for ambient air matrix effects. In practice, the two calibrations agree to within <2 to 5%.

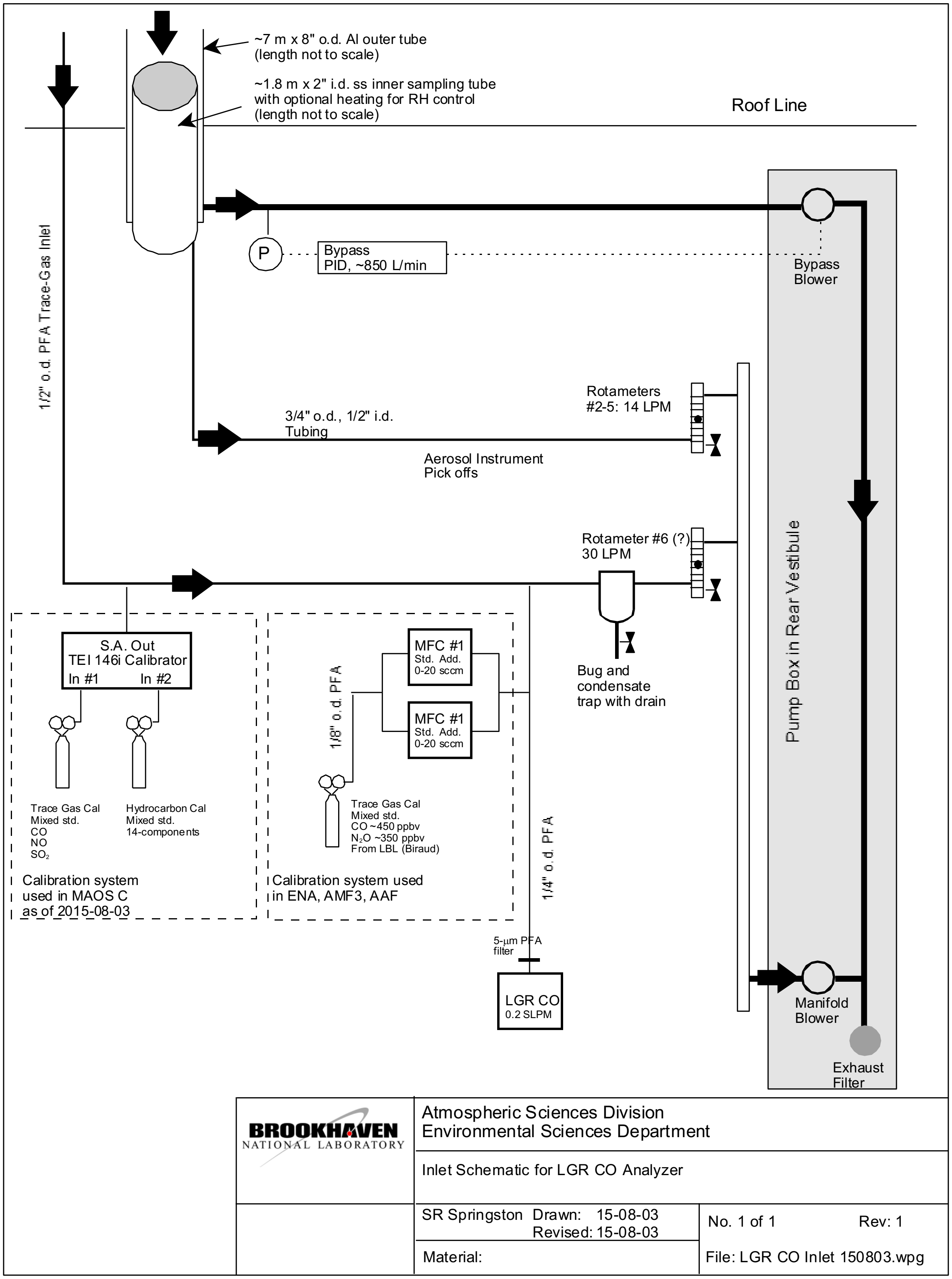

Figure 10. Ground inlet schematic.

9.0 Instrument/Measurement Theory

The following description is taken from the LGR manual:

> "Off-Axis ICOS utilizes a high-finesse optical cavity as an absorption cell, as shown in Figure 8. Unlike conventional multi-pass arrangements, which are typically limited to path lengths less than 200 meters, an Off-Axis ICOS absorption cell effectively traps the laser photon so that, on average, they make thousands of passes before leaving the cell. As a result, the effective optical path length may be several thousands of meters using high-reflectivity mirrors and thus the measured absorption of light after it passes through the optical cavity is significantly enhanced. For example, for a cell composed of two 99.99% reflectivity mirrors spaced by 25 cm, the effective optical path length is 2500 meters.
>
> "Because the path length depends only on optical losses in the cavity and not on a unique beam trajectory (like conventional multi-pass cells or cavity-ring-down systems), the optical alignment is very robust, allowing for reliable operation in the field. The effective optical path length is routinely determined by simply switching the laser off and measuring the necessary time for light to leave the cavity (typically tens of microseconds).
>
> "As with conventional tunable-laser absorption-spectroscopy methods, the wavelength of the laser is turned over a selected absorption feature of the target species. The measured absorption spectra are recorded and combined with measured gas temperature and pressure in the cell, effective path length, and known line strength, and used to determine a quantitative measurement of mixing ratio directly and without external calibration."

The following description is from the mentor:

> "This instrument poses challenges to measure zero concentration. Introducing a sample scrubbed of CO, N_2O, or H_2O causes the instrument to lose the spectroscopic lock on the absorbance line. When this happens, the instrument cannot measure the analyte and reports its 'missing value' of -999. For ambient measurements, this poses little difficulty since these analytes NEVER reach zero in the ambient air. (Note, the exception is arctic sampling of H_2O where values can dip below 150 ppmv.) With tuning by the vendor, the LGR CO Analyzer can measure quite low concentrations, and this does not present a problem except for calibrating the zero response.
>
> "When scrubbed zero air is introduced, no output value is given. The vendor claims this is not an issue as the zero is determined by first principles from on-peak/off-peak scanning of the laser line. As an analytical chemistry issue, a zero level is always desirable. During laboratory tests with one unit, the mentor was able to ascertain the zero was within ±0.5 ppbv, but it has not been possible to repeat this test with other LGR analyzers."

10.0 Setup and Operation of Instrument

The instrument is permanently installed in the AOS systems. Its installation is described below:

1. Physical mounting of the instrument in a shock-isolated 19-inch instrument rack

2. Plumbing of the sample line into the fast-flow ½-inch PFA trace gas manifold line with the associated 47-mm PFA filter and filter holder
3. Plumbing of the standard addition/replacement gas calibration MFCs (for AMF1, AMF2, MF3, ENA, SGP) or the older standard addition into the ½-inch PFA trace gas manifold line
4. Connection of the Keyboard/Video/Mouse inputs to the AOS KVM switch
5. Connection of the RS-232 output to the instrument computer
6. Connection of the 110-VAC power line to the appropriate Power Distribution Unit outlet.

Initialization involves only making sure the ½-inch PFA trace gas manifold line runs up the aerosol stack to under the 14-inch rain hat and turning on the power.

After power is turned on, the instrument performs self-checks and commences outputting data. This initialization period usually only takes ~5 minutes but can take as long as 10 to 15 minutes while the instrument cleans up old files.

11.0 Software

The instrument uses software running under Linux as written by LGR. ARM is not provided source code for this software. Occasionally, operators need to access this system under instructions from the vendor or mentor. This is done on a case-by-case basis.

Instrument control and data acquisition are performed by NI LabView-based software written by Brookhaven National Laboratory. For the current generation of instruments, the CO analyzer GUI also controls the mass flow controllers for standard addition/displacement calibrations.

12.0 Calibration

Calibration procedures are described earlier. These include daily standard additions in ambient air. In the newer systems, a 1-week displacement calibration is also performed. The displacement calibration is more direct and overflows the inlet with a calibration gas containing a known concentration of CO and N_2O. To date, the instruments have not been field-calibrated for H_2O. A span check is done daily 30-seconds after midnight UTC (00:00:30) for three minutes, and a weekly displacement calibration occurs 10 minutes after midnight UTC (00:10:00), also for three minutes.

Gaseous calibration standards are commercially available. The vendor-stated concentration is used as supplied. LBNL has supplied a standard of CO and N_2O, and the stated concentration is used. The mentor keeps a record of the cylinders supplied and their known concentrations.

Because the standard addition method requires knowledge of MFC and instrument flow calibrations, these are calibrated during mentor visits. MFCs are calibrated with a six-point calibration with triplicate measurements at each flow. Either a first principles bubble flowmeter (with corrections for temperature, pressure, and water vapor concentration) or a dry gas meter (standardized against the bubble flowmeter) is used to calibrate the instrument and MFC flows.

13.0 Maintenance

This instrument requires minimal maintenance. The mentor advises changing the inlet particle filter every two weeks. The filter is a 47-mm diam. 5-µm PFA membrane filter Type LS (see Figure 11).[1] Note that the filter is not directional (either side up). The filter is white and is packed in a stack separated by blue plastic spacers. DO NOT USE THE SPACER! USE THE WHITE FILTER! (This error has been made multiple times.)

Figure 11. 47-mm PFA filter holder. Note the arrow showing the flow direction.

Green filter-holder wrenches as shown in Figure 12 were delivered with the instrument. One end of the wrench goes over the orange locking ring and the other (smaller) end goes over the PFA body. When opening the holder, note (and report) if the previous filter appears damaged. The filter being replaced should have at most a faint circle of trapped dirt. If the circle is visibly dark, increase the change frequency and notify the mentor.

The ¼-inch PFA fittings on the ends of the filter have an integral ferrule in the nut (no separate ferrule needed). These are finger tightened, but should be quite snug on the ¼-inch PFA tubing.

The old filter may be disposed of in regular garbage.

[1] Millipore Catalog # LSWPO4700.

Figure 12. 47-mm filter holder wrenches.

14.0 Safety

There are no safety concerns that need to be considered when operating the unit under normal conditions. There is a Class IIIb laser inside, so the instrument should not be operated with the cover off. The LGR manual lists the warning shown in Figure 13.

WARNING! This Instrument contains a Class IIIB laser inside

There is a Class IIIB laser inside this instrument that complies with 21 CFR 1040.10 and 1040.11.

Users should take appropriate precautions to ensure that the laser is off when the instrument cover is removed.

Figure 13. Laser safety warning (from LGR manual).

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