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Carbon Monoxide Analyzer (CO-ANALYZER) Instrument Handbook

S Springston

August 2015

ARM CLIMATE RESEARCH FACILITY

DISCLAIMER

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S Springston, Brookhaven National Laboratory

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Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

AAF	ARM Aerial Facility
ACME	ARM Airborne Carbon Measurements
AMF	ARM Mobile Facility
AMF1	AMF associated with MAOS
AMF3	AMF to be located at Oliktok Point, Alaska
AOS	Aerosol Observing System
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
BCR	Baseline Change Request
BNL	Brookhaven National Laboratory
CO	Carbon Monoxide
CRDS	cavity ringdown spectroscopy
diam.	diameter
ENA	Eastern North Atlantic
GUI	Graphical User Interface
H_2O	water
IOP	intensive operational period
LBNL	Lawrence Berkeley National Laboratory
LGR	Los Gatos Research
MAOS	Mobile Aerosol Observing System (an intensively instrumented AOS)
mb	millibar
MFC	Mass Flow Controller
mm	millimeter
N_2O	Nitrous oxide
NIST	National Institute of Standards and Technology
NTP	Network Time Protocol
PFA	perfluoroalkoxy
ppm	parts per million
ppmv	parts per million by volume
sccm	standard cubic centimeters per minute
SLPM	standard liter per minute
UTC	universal coordinated time
VAC	Volts alternating current

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1.0 Instrument Title

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

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4.0 Instrument Description

As of 5 August, 2015, Los Gatos Research (LGR) $CO/H_2O/N_2O$ analyzer instruments (CO-ANALYZERs) were deployed in the Atmospheric Radiation Measurement (ARM) Aerial Facility (AAF), the third ARM Mobile Facility (AMF3) Aerosol Observing System (AOS), Eastern North Atlantic (ENA) AOS and Mobile AOS (MAOS-C).

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

Figure 2. Model 098-0014 (MAOS-C) (from LGR Manual).

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

The N_2O/CO analyzer uses LGR's patented Off-axis ICOS technology, which employs a high-finesse optical cavity as the measurement cell. LGR's technology has many proven advantages over conventional first-generation cavity ringdown spectroscopy (CRDS) techniques. In brief, since 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 for cleaning (CAREFULLY) the front surface mirrors. Analyzers are relatively inexpensive and inherently robust thermally and mechanically. In addition, since LGR's technology can record reliable absorption spectra over a far wider range of optical depths (absorbance values) than CRDS, 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 with directly through an ethernet connection, but the current Linux operating system installed does not support modern updates and poses a security risk.

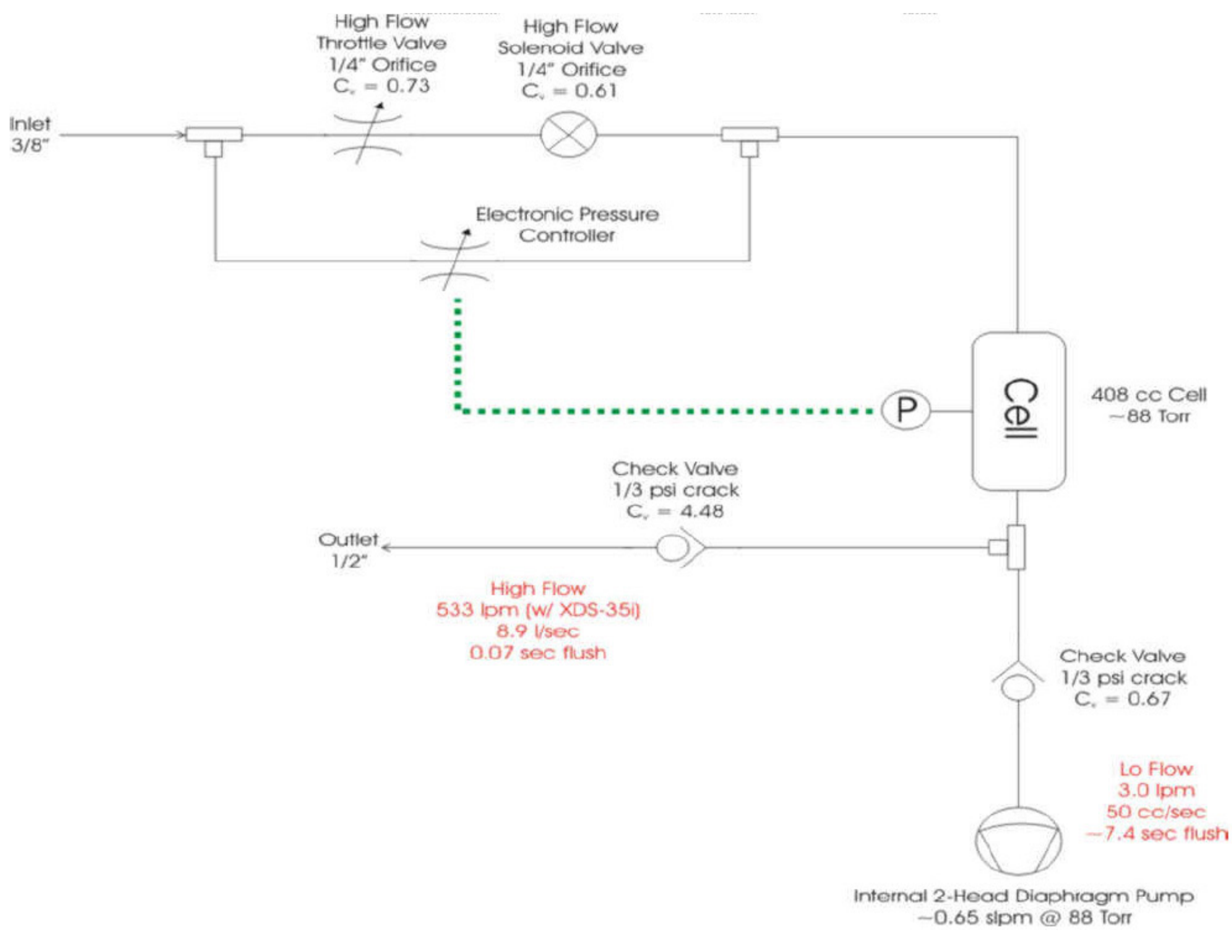


Figure 3. Internal flow schematic (from LGR Manual).

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

Modifications for ground measurements include:

1. Addition of a 47-mm x 5-µm Teflon filter on the inlet line.
2. Standard addition calibrations on a daily basis. Calibrations have varied by installation.

a) AAF – Originally a displacement calibration was performed every 30 minutes in parallel with the Picarro CO2/CH4 instrument. Currently (beginning in the ARM Airborne Carbon Measurements V [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.

b) 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.

c) ENA – 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.

d) 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 for 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-s resolution in units of ppbv in ambient air. Accompanying instrument outputs include sample and ambient temperatures and chamber pressure. Ancillary information from a custom calibration system are 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.

Meta data are now included in every hourly data file. The metadata are:

Row 1:	Filename
Row 4 (col 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:

Date Time	Primary Date/Time stamp yyyy-mm-dd hh:mm:ss as set by the instrument computer and referenced to the site NTP 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 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 previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
H2O	Mixing ratio of water vapor in ambient air (ppmv)
H2O_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), 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 previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), 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 previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
GasP	Gas pressure in the sample cell (torr)
GasP_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
GasT	Gas temperature in the sample cell (C)

GasT_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
AmbT	Temperature of the instrument interior (C)
AmbT_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.

The above channels 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 previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
LTCO	Unused
LTCO_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
AIN5	Unused
AIN5_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
AIN6	Unused
AIN6_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
AIN7	Unused
AIN7_se	Standard error. This is the standard deviation of previous measurement over the averaging period. Since instrument data is recorded at the instrument frequency (1s), this error is 0.
FitFlag	Used internally for processing

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

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'.
Flow 1 setpoint	The setpoint for the first MFC. This should not change.
Flow 1 read	This is the actual read-out 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).
Valve 2 position	Valve 2 is a 0-2.0 SLPM Mass Flow Controller (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'.
Flow 2 setpoint	The setpoint for the second MFC. This should not change.
Flow 2 read	This is the actual read out 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.
Comment	This field is the last field in the datastream. It allows operators to enter free form text from the Graphical User Interface at any time. Operational notes or disruptions may be entered here.

These data are saved unaltered from what is produced by the instrument. Processing of the raw data must be able to deal with more than 1 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. Since neither the instrument clock nor the instrument computer clock are perfect, minor irregularities (dithering) in the output data s\tream can occur.

6.1.2 Mentor AC/QCd Datastream

Mentors provide data that has been processed from the 'raw' data stream. In general, data is delivered in 1-month chunks (for the AAF, the division is by flight). For each month (or other period) three files are produced. The naming convention is:

[site][platform][subsite].[species].[resolution].[version].[date].[time].[processing level].[delimiter]{.log.txt | .plots.pdf}

Where:

[site]	The site of the measurement (usually the 3-letter specifier of the nearest airport)
[platform]	The structure used for the instrument (aos | maosa | maosc)
[subsite]	The subsite of the sampling site (m1 : main site | s1 : supplemental site)
[species]	Species measured – for this instrument this is 'co'

[resolution]	[xxs] (xx: two significant figures, s: time units string – s = seconds, m = minutes, h = hours, d = day, w = week, M = month) Typically this is always s or m
[version]	Version of this data. Always use the highest version number with this name.
[date]	Date of first point in file (yyyymmdd)
[time]	Time of first point in file (hhmmss)
[processing level]	This is either ‘raw’ for ‘raw’ data or ‘m02’ for Mentor QA/QC’d data with only ambient measurements (zeros and calibrations removed), vetted and all appropriate calibration factors used in processing.
[delimiter]	Typically this is ‘tsv’ for tab-separated values, but could be ‘csv’ for comma-separated values.
{.log.txt | .plots.pdf}	Optional extension. In addition to the data file, the mentor prepares a .log.txt file containing explanations of processing unique for this time period and a plots.pdf file with time series plots of processed data.

The data for this instrument (both .raw and .m02) follow the file structure used for most DOE/BNL/AOS instruments:

File Structure:

Row 1:	Filename
Row 4 (col 1 only):	ARM Climate Research Facility
Row 5:	SitePlatform
Row 7:	Last revised date
Row 9:	Instrument
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

Raw data now (beginning in 2014) have all the metadata described above. Data is given in an arbitrary number of columns. The first column is date/time.

Time - Time is reported in UTC as set by an NTP server. Following convention, the time is the beginning of the period. The parameter reported at this time is the average of all points >= the time and < the next time. Data are reported at 1- s resolution. All non-operational periods have been removed (empty field or NAN). As follows convention, data are reported as tab-delimited ASCII files. Files are formatted such that they are self-documenting.

Data Columns (for mentor-QA/QC’d data):

Column 1: Date Time – All times are in UTC as yyyy-mm-dd hh:mm:ss{.ss} and are the beginning of the time period. All data reported here correspond to data from samples taken >= this time and < than this time + the data increment.

Column 2: [CO] – Mixing volume of CO in ambient air (no water vapor correction). This is this instrument's primary measurement.

Column 3: [N2O] - Mixing volume of N_2O in ambient air (no water vapor correction).

Column 4: [H2O] – Mixing volume of H_2O in ambient air

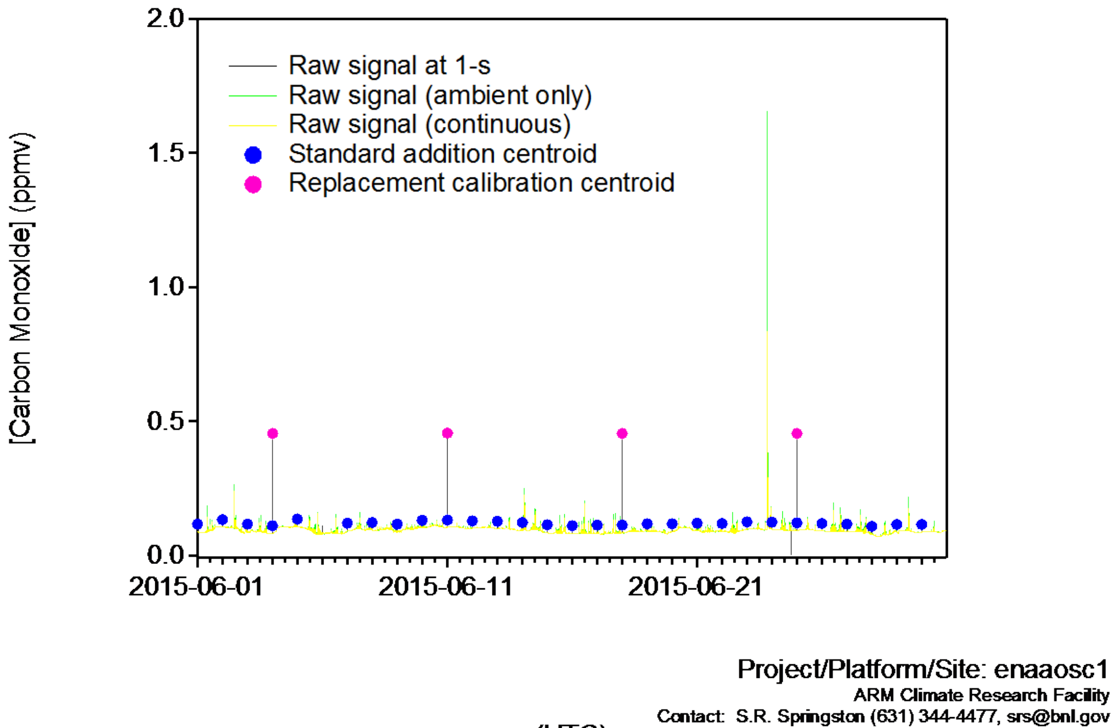
Note: Periodically, IOP PIs have requested mixing volumes reported as calculated in dry air. When this is done, there are notes in the metadata and a Baseline Change Request (BCR) should be filed.

6.2 Data Ordering

$CO/H_2O/N_2O$ data collected are distributed through the ARM Data Archive and are presently updated monthly.

6.3 Data Plots

Los Gatos Model ICOS CO/N2O/H2O Analyzer



(UTC)

Figure 4. Raw CO data for one month.

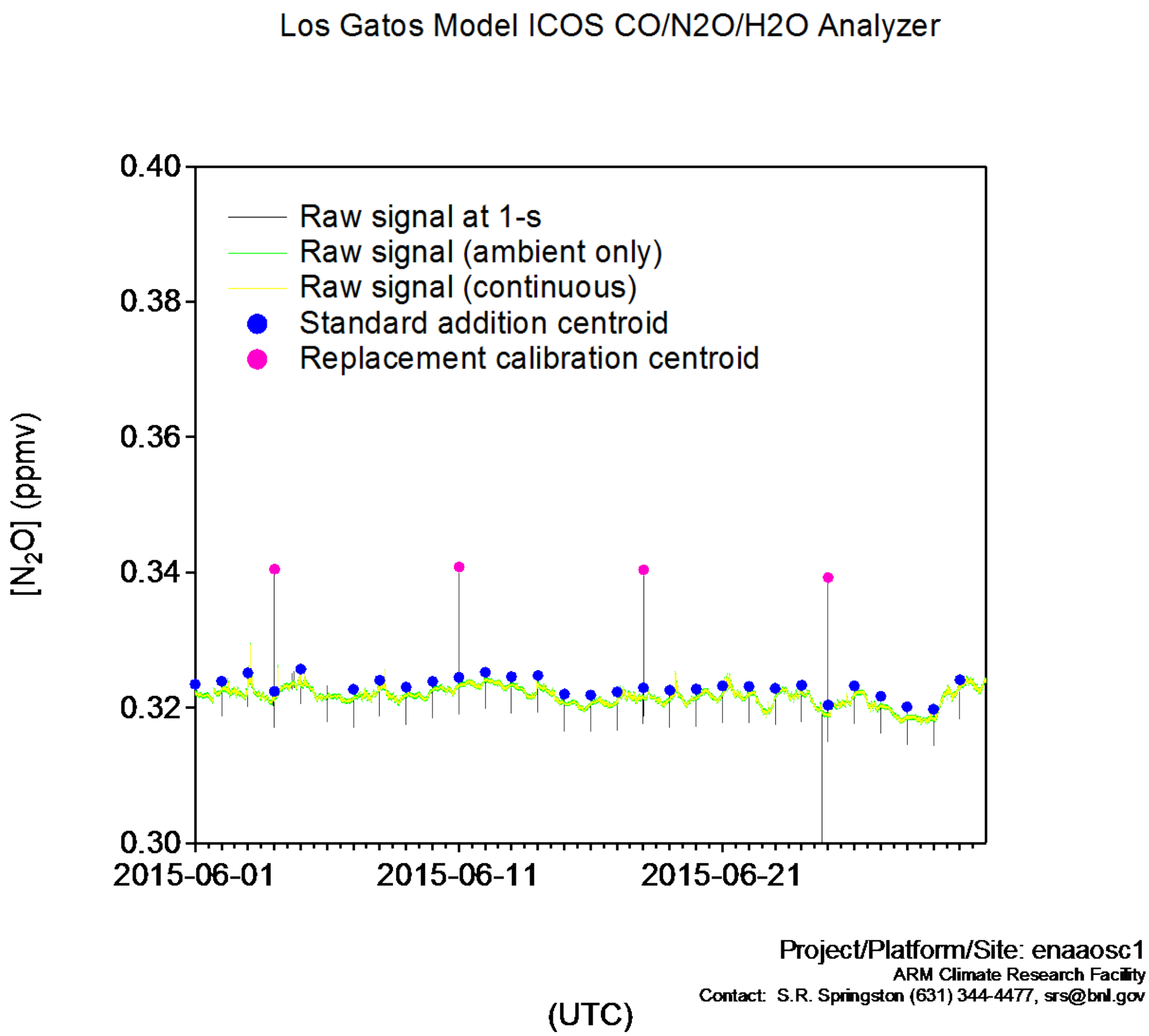


Figure 5. Raw N_2O data for one month.

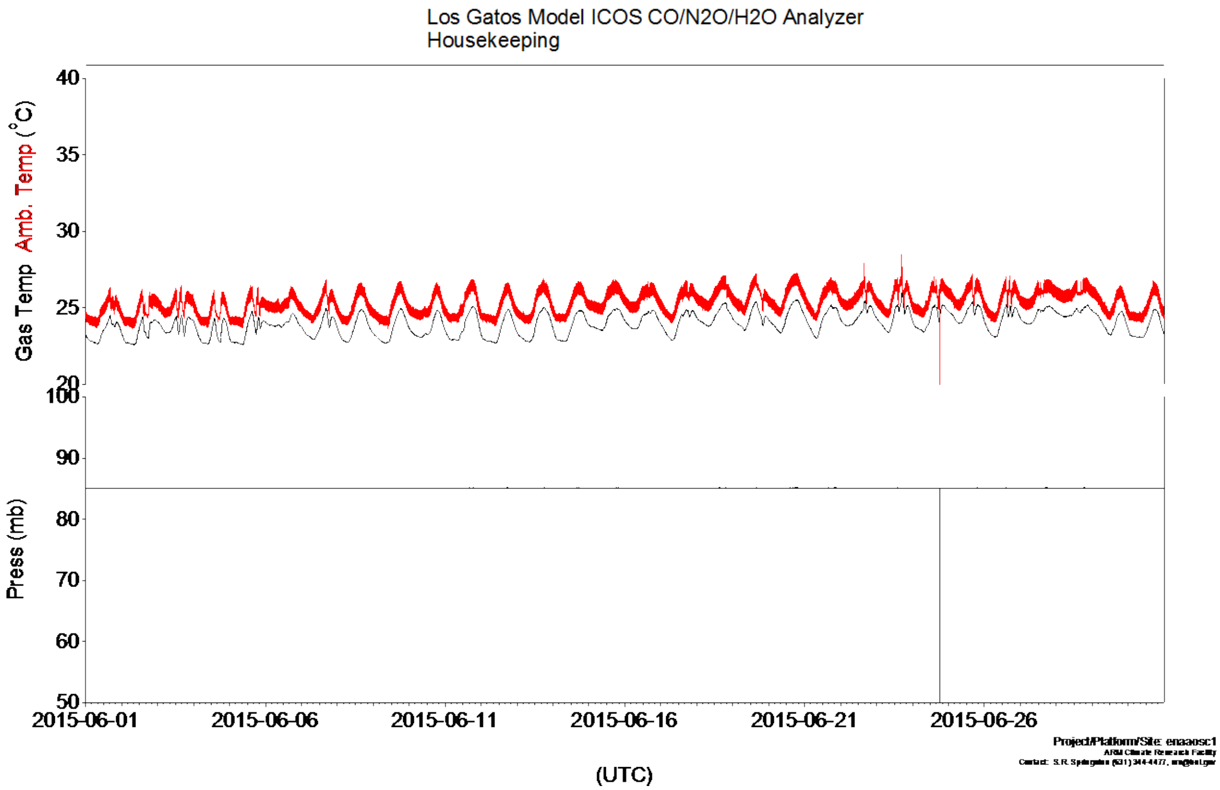


Figure 6. Housekeeping data for one month.

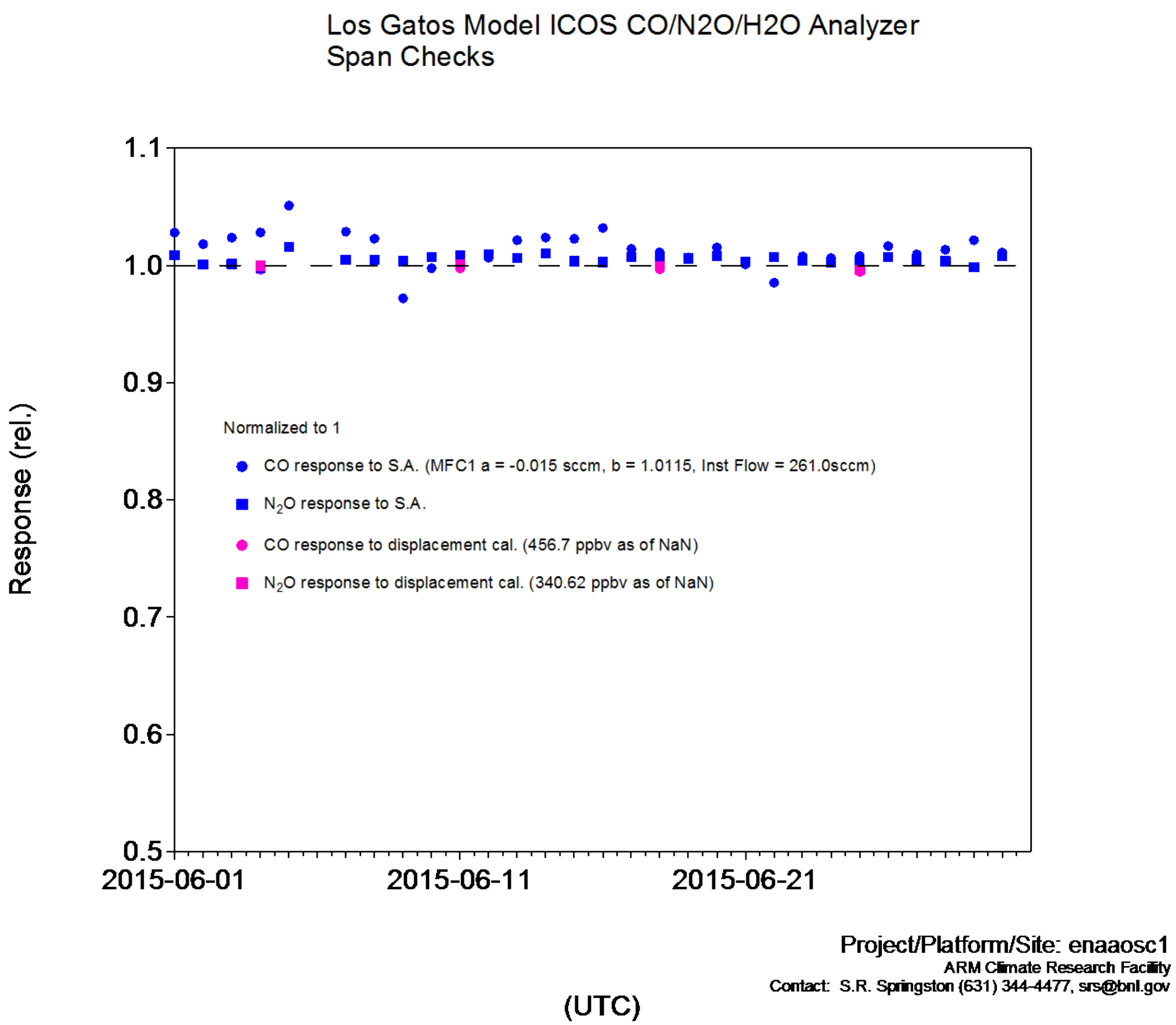


Figure 7. Calibration results for one month.

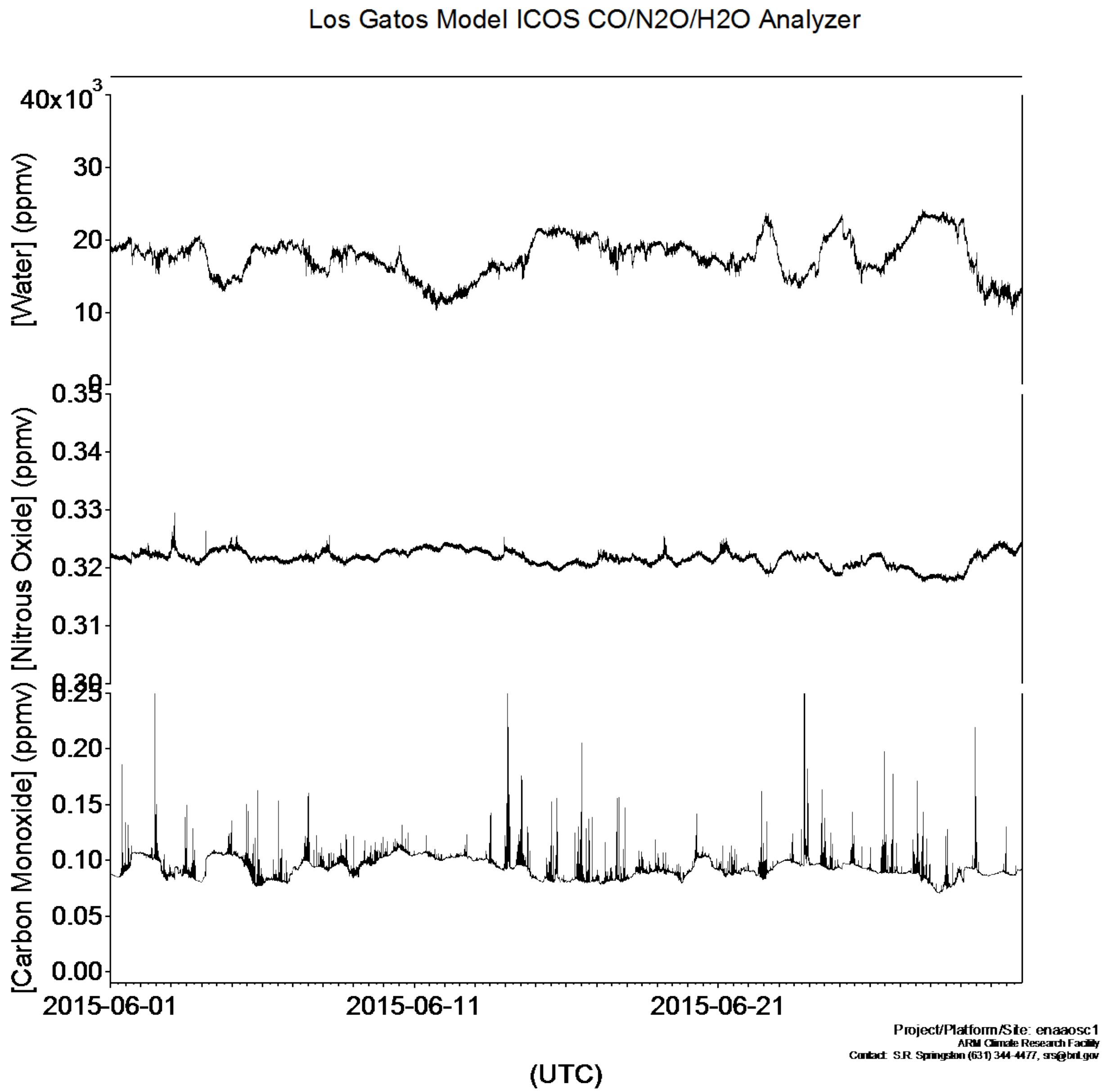


Figure 8. Processed data for one month.

6.4 Data Quality

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

The second level of data quality is 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 1-2% 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 1-2% (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 IOPs 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 [BNL]). The gaseous standards for CO are either NIST-traceable, commercial standards or a shared CO, N_2O standard provided by Sebastien Biraud of Lawrence Berkeley National Laboratory (LBL).

Since 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 tuning, the instrument will not operate below ~30-40 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. Laboratory tests with scrubbed zero air have shown a y-intercept to be within +/- 0.2 – 0.3 ppbv for CO.

7.0 Technical Specification

7.1 Units

The measured quantity of interest is the mixing volume of 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 since 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 ~50-60 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 (noncondensing) from ~<2000-5000 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 ±2 ppbv or ±2%, whichever is greater. Under ideal circumstances (recent flow calibrations and high-quality standard), evidence points to better accuracy approaching ±1% for both gases.

7.4 Repeatability

Precision (repeatability) is given here as the noise of the 1-s 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 since 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, it is documented.

7.7 Output Values

Described in Section 6.0.

8.0 Instrument System Functional Diagram

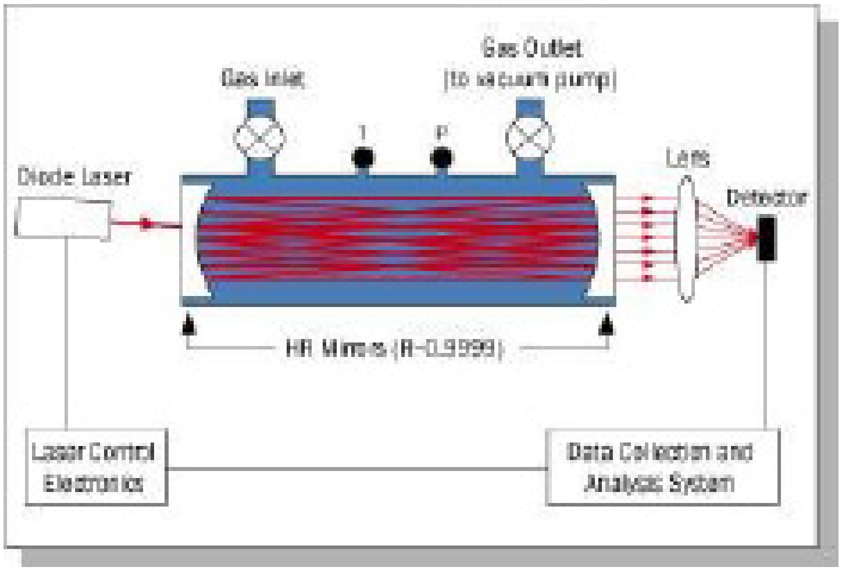


Figure 9. Diagram of optical cell (from LGR Manual).

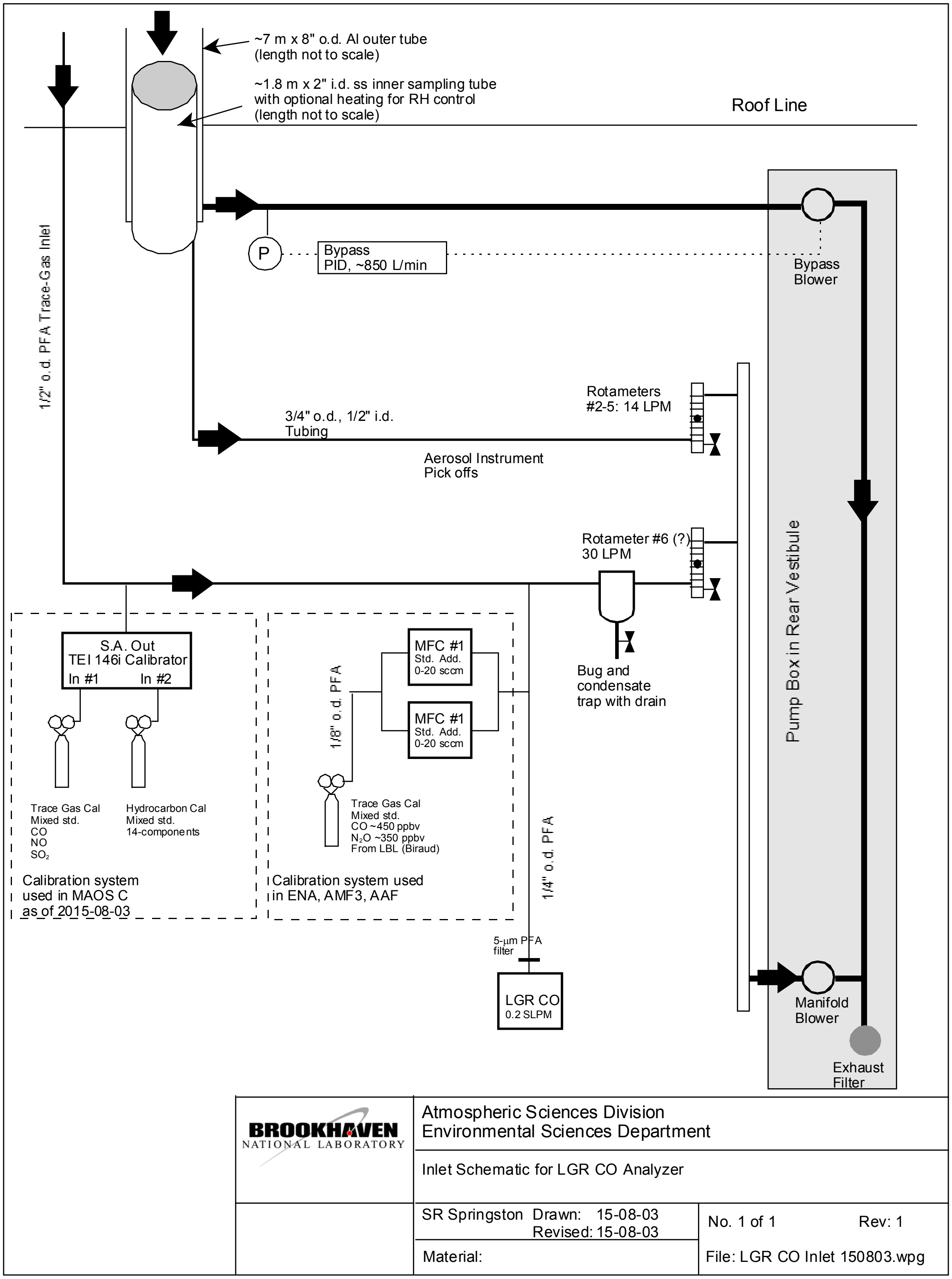


Figure 10. Ground inlet schematic.

As of 3 August, 2015, there were two calibration configurations. In MAOS C, a standard addition to the hi-flow 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 +/- 5-10%.

In newer installations (AMF3, ENA and SGP) a dual Mass Flow Controller system is used to add sample to the much lower instrument inlet flow. A standard addition is performed 1/day using ~20 sccm of calibration gas. This depends on knowing the MFC flow AND 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 <2-5%.

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 two-hundred 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 multipass 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 determined routinely by simply switching the laser off and measuring the necessary 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 is recorded and combined with measured gas temperature and pressure in the cell, effective path length, and known line strength, used to determine a quantitative measurement of mixing ration directly and without external calibration.

From the mentor:

This instrument poses challenges to measure zero concentration. Introducing 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. (With the exception of 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 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. This includes:

1. Physical mounting of the instrument in a shock-isolated 19” instrument rack,
2. Plumbing of the sample line into the fast-flow ½” 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 AMF3, ENA, SGP) or the older standard addition into the ½” PFA trace gas manifold line (currently in MAOS-C),
4. Connection of the keyboard/video/mouse inputs to the AOS KVM switch,
5. Connection of the RS-232 output to the instrument computer, and
6. Connection of the 110 VAC power line to the appropriate Power Distribution Unit outlet.

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

After power is turned on, the instrument goes through self-checks and commences putting out data. This turn on period usually only takes ~5 min, but can run 10-15 min periodically when 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.

A Graphical User Interface (GUI) has been written by BNL for the instrument computer (‘brick’) acquiring data from the LGR analyzer. This GUI is similar to other AOS instrument GUIs. For the instrument operating in MAOS C, the standard addition is controlled by the GUI for the MAOS C Oxides of Nitrogen Detector. For the current generation of instruments, the CO analyzer GUI also controls the 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 over -loods 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.

Gaseous calibration standards are commercially available. The vendor-stated concentration is used as supplied. Recently Lawrence Berkeley National Laboratory has supplied a standard of CO and N_2O and the stated concentration is used.

Because the standard addition method requires knowledge of MFC and instrument flow calibrations, these are calibrated during mentor visits. MFCs are calibrated with a 6-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

Maintenance is minimal on this instrument. The mentor advises changing the inlet particle filter every 2 weeks. The filter is 47-mm diam. 5-µm PFA membrane filter Type LS (Millipore Catalog # LSWPO4700). 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 flow direction.

Figure 12. 47-mm filter holder wrenches.

The green filter holder wrenches were delivered with the instrument. One end 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” 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” PFA tubing.

The old filter may be disposed of in regular garbage.

14.0 Safety

Unit has no safety concerns during normal operation. There is a Class IIIB laser inside. Instrument should not be operated with the cover off. The LGR Manual lists this warning:

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).

15.0 Citable References

N/A

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