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Particle Soot Absorption Photometer (PSAP) Instrument Handbook

SR Springston

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ARM
CLIMATE RESEARCH FACILITY

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Acronyms and Abbreviations

AAF	ARM Aerial Facility
ADC	analog-to-digital converter
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
BNL	Brookhaven National Laboratory
ENA	East North Atlantic
EPROM	erasable programmable read-only memory
GUI	Graphical User Interface
HEPA	high-efficiency particulate air
LED	light-emitting diodes
lpm	liters per minute
MAOS	Mobile Aerosol Observing System
MFC	Mass Flow Controller
MFM	Mass Flow Meter
NTP	network time protocol
PSAP	Particle Soot Absorption Photometer
QA	quality assurance
QC	quality control
SGP	Southern Great Plains
slpm	standard liters per minute
UTC	Coordinated Universal Time

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1.0 Instrument Title

Particle Soot/Absorption Photometer (3-λ PSAP). Instrument's front panel is pictured in section 4.0.

2.0 Mentor Contact Information

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As of 2014, Radiance Research announced the PSAP would be discontinued and the company would no longer be available for support on a regular basis. Given the long history of PSAP operation in Atmospheric Radiation Measurement (ARM) (since 1992 at the Southern Great Plains [SGP] observatory), the ARM Climate Research Facility will continue to operate the existing instrument until a substitute has been accepted.

4.0 Instrument Description

Radiance Research PSAPs as described in this Handbook are deployed in the second ARM Mobile Facility (AMF1) aerosol observing system (AOS), which was formerly known as mobile aerosol observing system (MAOS)-A, AMF2 AOS, AMF3 AOS, ENA AOS, MAOS-A, and SGP AOS. An earlier version of the PSAP is currently operated in the ARM Aerial Facility (AAF). The original SGP AOS site (AOS00) used an older PSAP but has been discontinued. The older SGP instrument is covered in a separate handbook.

Figure 1. Front panel (AMF2, AMF3, ENA, MAOS-A).

The PSAP determines the optical extinction coefficient for absorption at three wavelengths. The method is based on measuring optical transmittance through a glass/cellulose filter over time as particles are deposited.

As discussed elsewhere (Schmid et al. 2006; Virkkula et al. 2005; Anderson et al. 2003; Anderson et al. 1999; Bond et al. 1999), the PSAP technique measures the particle absorption coefficient (σ_{AP}) as a function of the decrease in transmittance, *Tr*, over time as particles accumulate on the filter; that is:

$$\sigma_{AP} \propto \frac{Tr_{t-\Delta t} - Tr_t}{\Delta t} \tag{1}$$

where Tr_t is the sample transmittance for the current averaging period and $Tr_{t-\Delta t}$ is the sample transmittance for the previous averaging period, Δt.

The filter transmittance is calculated (Virkkula et al. 2005) for each wavelength as:

$$Tr = \frac{\left(\Sigma Sig / \Sigma Ref\right)}{\left(\Sigma Sig / \Sigma Ref\right)_{t=0}} \tag{2}$$

where ΣSig and ΣRef are the detector outputs for the signal and reference channels summed over the same period, Δt. The reference channel includes an identical filter downstream of the sample channel and is illuminated by the same light source in order to further reduce certain common-mode noise sources such as light emitting diodes (LED) output fluctuations and changes in the optical properties of the filter media. The denominator of Eq. 2 normalizes the transmittance to the value of a new filter. In operation, the filter is changed when $Tr < 0.7$ (Bond et al. 1999). Furthermore, the change in *Tr* over Δt is << 1 and therefore the simplification of $\ln \frac{Tr_{t+\Delta t}}{Tr_t} = Tr_{t+\Delta t} - Tr_t$ was used to derive Eq. 1 from Beer's law.

A single, three-LED assembly provides light simultaneously through the sample and reference filter holder. The filters are from PALL Life Sciences (E70-2075W, VWR Part Number 21431-350). The vendor specifies this filter and correction factors in the processing are calibrated for this filter, so do not substitute. The sample filter collects all the ambient aerosol. The reference filter then is exposed to the same (aerosol-free) air as the sample filter. This two-filter system allows for removal of all common-mode noise (such as humidity).

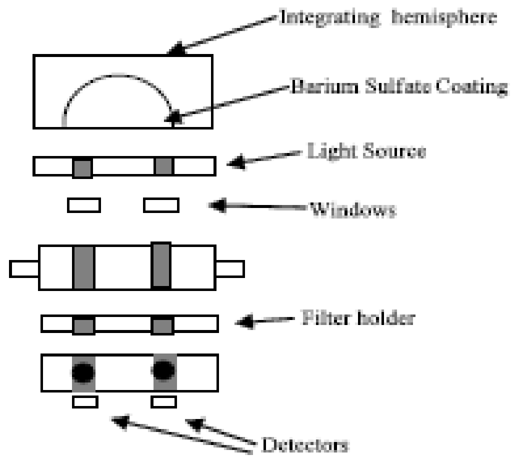

Figure 2. Optical assembly.

The three absorbances are measured by alternating between three illuminating LEDs. Nominally, the output of these three LEDs is listed as 470, 522, and 660 nm. Spectroscopic analysis of the output revealed a slightly different output:

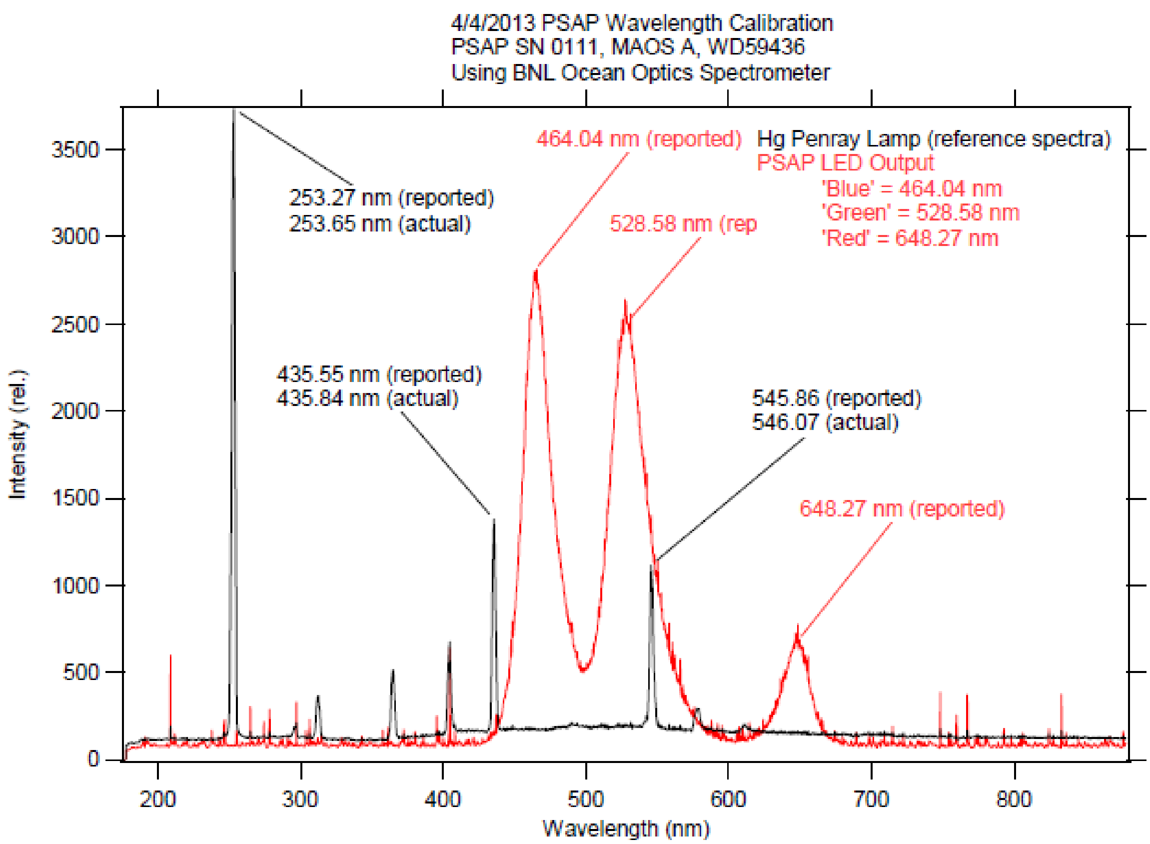

Figure 3. Measurement of LED outputs relative to Hg lamp.

The measured LED outputs shown here should be considered as the true absorbance wavelengths. These wavelengths are included in the metadata of all PSAP data files.

The 3-λ PSAP includes a mass flow meter (MFM) after the optical cell. All measured absorbances are scaled by the measured flow rate. A nominal flow rate of 1.0 slpm is maintained. The internal software of the PSAP uses a two-segment spline calibration fit of the MFM to calculate the true flow. In the AOS systems, a more accurate three-parameter parabolic fit is used to calculate the true flow. The MFM is calibrated annually or more frequently if circumstances change.

The internal software of the PSAP uses a nominal filter area to calculate the absorbance coefficient. This area is a default value assumed by the manufacturer. A more accurate measurement was done for each individual unit by the mentor.

The more accurate calibrated flow coefficients and filter area are used to calculate the absorbance coefficients.

In the field, the operator must monitor the front-panel read-out to read the nominal transmittance of the filter.

The 3-λ PSAPs described here use EPROM version 2.03. This output includes a full 20-bit-resolution measurement of the detector intensity at all three wavelengths plus the dark current of both the sample and reference light paths at 1-s resolution. Output of the PSAP is through an RS-232 serial port to the instrument computer. For historical reasons, the PSAP does not output all the relevant data in a single format. For this reason, three separate files are recorded: “R”, “F”, and “I”.

Modifications of the stock instrument produced by Radiance Research include:

1. A slight easing of sharp edges in the filter holder to prevent O-ring tearing.
2. Replacing of the coarse metering valve with a micrometer-driven flow valve (Swagelok) allowing the nominal flow rate to be adjusted to 1.000 ± 0.001 slpm.
3. Addition of an impactor and Nafion drier upstream of the sampling port.
4. Addition of a 0-2 slpm “Dilution” mass flow controller (MFC) immediately upstream of the sampling port.

5.0 Measurements Taken

The primary measurement output from the PSAP is the light intensity at three wavelengths plus a dark current measurement for the sample and reference filters. An ancillary measurement of mass flow is also recorded. The addition of the dilution system adds a set point and read point from the dilution MFC.

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.

Metadata 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

There are three serial output records saved. Each of the three is saved in its own file. The three files are "R", "F" and "I". All three are read (sequentially each second) into a LabView vi. Once per hour, the LabView vi outputs three files as named:

[site][platform][subsite].[species].[resolution].[version].[date].[time].[processing level].[delimiter]

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 either: 'psap3w' for the type "F" files 'psap3wI' for the type "I" files 'psap3wR' – for the type "R" files
[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. For the PSAP this should be 01s.

[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 'raw' for 'raw' data.
[delimiter]	This is 'tsv' for tab-separated values.

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 Operator has not set the instrument time. This value is usually discarded.

For type "F" (fast) files the data uses a short averaging time. The letter 'F' is not output. The 'F' is only used by the vi to determine which record type this is. Instead the vi adds the current date/time stamp field to the beginning of each record. Fields are:

1	date/time at end of avg interval, YYMMDDhhmmss.
2	Blue "b1999 corrected" Babs, inverse megameters.
3	Green same.
4	Red same.
5	Blue filter transmission relative to a clean filter.
6	Green transmission.
7	Red transmission.
8	Current mass flowrate over last second in lpm.
9	Average mass flowrate over 2 x averaging interval. May be set manually (faked) or forced to min 0.1 lpm.
10	Boxcar averaging interval in seconds.
11	Various status flags as a 16 bit hex #.

status bits set for condition:

0x8000 = any signal or ref current was over range for any boxcar in 2 x avg interval, data may be wrong.
0x4000 = blue signal or ref (1 sec avg) > 950K, warning, close to full scale, should lower gain.
0x2000 = green high 0x1000 = red high 0x0800 = unused, zero
0x0400 = blue signal or ref < 150K, warning, should raise gain. 0x0200 = green low
0x0100 = red low
0x0080 = Babs values are "b1999" corrected for filter Bscat. 0x0040 = unused, zero
0x0020 = using a fake avg flowrate for calculations. 0x0010 = real avg flow < 0.1 lpm, using 0.1 lpm for calcs.
0x0008-1 = ADC full scale gain setting, 0-5. Higher is more sensitive.

BNL added three additional fields to the type "F" file.

12	Dilution valve position [closed | open]. If this field is 'closed' dilution is to be considered off.
13	Dilution MFC set point (in sccm). A nominal reading of the setpoint from the digital MFC.
14	Dilution MFC read point (in sccm). A nominal reading of the flow read-out from the MFC. Use a current calibration slope and intercept to convert the nominal reading to a calibrated reading. If the flow rate is < ~25-30 sccm, the dilution must be taken to be 'closed'.

For type "I" (information) files. There are 60 sets of fields selected by the current timestamp second. The fields are separated by commas, with no whitespace and surrounded by double quotes. The letter 'I' is not output. The 'I' is only used by the vi to determine which record type this is. Instead the vi adds the current date/time stamp field to the beginning of each record. The instrument time (in the second field) is used to tell which set of fields follows.

Here is a sample:

```
1 ------2--------3-(quoted string, fields vary)---
I 100111153800      "00,0d,00a9c94a,160d,100111153800,B1999:ba=b0/(k1*Tr+k0)"
I 100111153801      "01,7ac4d869fb,c5facfad96,1913b0,00,K0=0.866,K1=1.317"
I 100111153802      "02,7ac4d7c0b2,c5face2d7a,1913b0,00,area=17.81"
I 100111153803      "03,7ac491206d,c5fa8dfec7,1913b0,00"
I 100111153804      "04,11,00a9e4ce,1611,000000,0dbba0,03,100111143730"
I 100111153805      "05,7ac50b69fb,c626c8bb96,1946b0,00,0.999"
I 100111153806      "06,7ac50ac0b2,c626c73b7a,1946b0,00,0.999"
I 100111153807      "07,7ac4c4206d,c626870cc7,1946b0,00,0.999"
I 100111153808      "08,15,00aa0052,1615,000000,0dbba0,03,100111105421"
I 100111153809      "09,7ac53e69fb,c652c1c996,1979b0,00,1.106"
I 100111153810      "10,7ac53dc0b2,c652c0497a,1979b0,00,1.106"
I 100111153811      "11,7ac4f7206d,c652801ac7,1979b0,00,1.106"
I 100111153812      "12,19,00aa1bd6,1619,000000,0dbba0,03,200302143858"
I 100111153813      "13,7ac57169fb,c67ebad796,19acb0,00,1.000"
I 100111153814      "14,7ac570c0b2,c67eb9577a,19acb0,00,1.000"
I 100111153815      "15,7ac52a206d,c67e7928c7,19acb0,00,1.000"
I 100111153816      "16,1d,00aa375a,161d,000000,0dbba0,03,200302143321"
I 100111153817      "17,7ac5a469fb,c6aab3e596,19dfb0,00,1.106"
I 100111153818      "18,7ac5a3c0b2,c6aab2657a,19dfb0,00,1.106"
I 100111153819      "19,7ac55d206d,c6aa7236c7,19dfb0,00,1.106"
I 100111153820      "20,21,00aa52de,1621,000000,0dbba0,03"
I 100111153821      "21,7ac5d769fb,c6d6acf396,1a12b0,00,mf0p0=1000"


I 100111153822      "22,7ac5d6c0b2,c6d6ab737a,1a12b0,00,mf0p3=1240"
I 100111153823      "23,7ac590206d,c6d66b44c7,1a12b0,00,mf2p0=2600"
I 100111153824      "24,25,00aa6e62,1625,000000,0dbba0,03"
I 100111153825      "25,7ac60a69fb,c702a60196,1a45b0,00"
```

```
I 100111153826        "26,7ac609c0b2,c702a4817a,1a45b0,00"
I 100111153827        "27,7ac5c3206d,c7026452c7,1a45b0,00"
                      <second 28-55   snipped >
I 100111153856        "56,45,00ab4a82,1645,000000,0dbba0,03,ver=2.03"
I 100111153857        "57,7ac7a269fb,c8626e7196,1bddb0,00,opt=c000"
I 100111153858        "58,7ac7a1c0b2,c8626cf17a,1bddb0,00,dbg=0000"
I 100111153859        "59,7ac75b206d,c8622cc2c7,1bddb0,00,romcsum=1b01"
I 100111153900        "00,49,00ab6606,1649,100111153900,B1999:ba=b0/(k1*Tr+k0)"
I 100111153901        "01,7ac7d569fb,c88e677f96,1c10b0,00,K0=0.866,K1=1.317"
I 100111153902        "02,7ac7d4c0b2,c88e65ff7a,1c10b0,00,area=17.81"
I 100111153903        "03,7ac78e206d,c88e25d0c7,1c10b0,00"
```

In the quoted string, field 1 is seconds 0-59 from the clock, used to select the source and format of the following fields.

Data is integrated into a 256 boxcars in a circular array.

The ADC data and flow summed over one second and added to the previous boxcar as unsigned integers, so box[t mod 256] - box[(t-n) mod 256] ->sum over n seconds. The data from every fourth boxcar is output so one can calculate absorption over a minimum interval of 4 seconds.

Faster response can be calculated from the 1/second "R" records.

For each record (field1 mod 4) selects flow,time,dark,gain or blue/green/red sig,ref,number of samples,overflows.

field1 mod 4 == 0: flow/time/dark/gain
--1,-2,----3---,--4-,---5--,---6--,-7 "24,25,00aa6e62,1625,000000,0dbba0,03"
field2 = 1 byte unsigned hex current boxcar index. Increments each second, wraps 0xff (255) -> 0.
field3 = 4 byte unsigned hex boxcar sum of flowrate lpm x 1e5. field4 = 2 byte unsigned hex boxcar sum of seconds,
delta field3/delta field4 / 1e5 -> average flow, lpm.
field5 = 3 byte signed hex signal dark current, 1 sec avg, not boxcar sum. field6 = 3 byte signed hex reference dark current, 1 sec avg, not boxcar sum. field7 = 1 byte unsigned hex current ADC gain setting.
On the minute, when field1 == 0, fields5-7 are replaced with the date and Bscat correction function (see below).
field1 mod 4 == 1-3: adc channel, from same boxcar index as previous flow/time/dark data.
--1,-----2----,-----3----,---4--,-5
"25,7ac60a69fb,c702a60196,1a45b0,00" field1 mod 4 == 1: blue
"26,7ac609c0b2,c702a4817a,1a45b0,00" field1 mod 4 == 2: green
"27,7ac5c3206d,c7026452c7,1a45b0,00" field1 mod 4 == 3: red

field2 = 5 byte unsigned hex boxcar sum of signal adc, full scale = 2^20 for each conversion.
field3 = 5 byte unsigned hex boxcar sum of reference adc.
field4 = 3 byte unsigned hex boxcar sum of number of conversions added to this bin TIMES 16!
field5 = 1 byte unsigned hex sum of sig/ref conversion over range flags seen.
On each conversion, if either sig or ref over range is set, both are discarded and the sample count will not increment. A few of these will not affect the averages as the ratio is used.

The ADCs run in the "unsigned + offset" mode. The ADC zero is offset to 4096 so this must be subtracted from the delta boxcar adc sums.
Do delta field2/3 boxcars - (delta field4 boxcars * 256), remember field4 is samples times 16.
Additional fields are appended to these selected by field1, 0-59 seconds. They show software config info and various constants and clean filter xmsns used in the calculations.

When field1 == 0:
-------------------,-----5------,----6-----------------
"00,0d,00a9c94a,160d,100111153800,B1999:ba=b0/(k1*Tr+k0)"

field5 = date now, at end of avg interval, YYMMDDhhmmss.
field6 = function of transmission for correction of Bscat effect in filter. ba = corrected (bap), b0 = ext ratio from delta xmsn, Tr = xmsn.

field1 == 1:
-----------------------------------,----6---,---7----
"01,7ac4d869fb,c5facfad96,1913b0,00,K0=0.866,K1=1.317"

The constants in the above function.

field1 == 2:
-----------------------------------,----6-----
"02,7ac4d7c0b2,c5face2d7a,1913b0,00,area=17.81"
The filter area to scale volume to column length, in sq. mm.

field1 == 4-7
--------------------------------------,-----8------
"04,11,00a9e4ce,1611,000000,0dbba0,03,100111143730" time of reset
-----------------------------------,--6--
"05,7ac50b69fb,c626c8bb96,1946b0,00,0.999" blue sig/ref
"06,7ac50ac0b2,c626c73b7a,1946b0,00,0.999" green
"07,7ac4c4206d,c626870cc7,1946b0,00,0.999" red
The time of the last xmsn reset on clean filters and the b/g/r sig/ref to normalize xmsns to 1.0. Each time it is set the previous values and time are pushed up the list and the oldest is lost.

field1 == 8-11 second newest xmsn reset. field1 == 12-15 third newest.
field1 == 16-19 fourth newest.

Older sig/ref “clean” can show if the new reset is much changed, perhaps dirty/two filters, and could be used to recalculate Bap if the “clean” transmission is accidentally reset on dirty filters.

field1 == 21-23
-----------------------------------,---- 6----
"21,7ac5d769fb,c6d6acf396,1a12b0,00,mf0p0=1000" millivolts for 0 lpm
"22,7ac5d6c0b2,c6d6ab737a,1a12b0,00,mf0p3=1240" for 0.3 lpm
"23,7ac590206d,c6d66b44c7,1a12b0,00,mf2p0=2600" for 2.0 lpm Flowmeter calibration constants.

field1 == 56-59
-----------------------------------,---- 6---- "56,45,00ab4a82,1645,000000,0dbba0,03,ver=2.03"

"57,7ac7a269fb,c8626e7196,1bddb0,00,opt=c000" "58,7ac7a1c0b2,c8626cf17a,1bddb0,00,dbg=0000" "59,7ac75b206d,c8622cc2c7,1bddb0,00,romcsum=1b01"

For type "R" (Raw format) files, the last 1 sec sums of signal and reference ADC values, the number of ADC readings summed, the mass flowmeter output in millivolts and LPM and hex status flags (see the 'F' records) are output. The letter 'R' is not output. The 'R' is only used by the vi to determine which record type this is. Instead the vi adds the current date/time stamp field to the beginning of each record in field 1.
The number of adc samples varies with the adc gain setting.
Divide the sig/ref sum by the sample count for average 20 bit ADC readings.
This is the data added to the boxcar integrator and can be used to do your own data reduction.

An example with the fields labeled, split at the "\":

1 ------2----- ----3--- ----4--- -5- -6 ---7---- ----8--- -9- 10 ---11---\ R 100111142547 058d3e6c 05053c7d 0cc 00 058d3d76 05053b38 0cc 00 058d3eaf\

---12--- -13 14 ---15--- ---16--- -17 18 -19- --20- -21-
05053c5b 0cc 00 ffffed7a fffff1ed 0cc 00 2577 1.971 0083

1	"R" record type identifier. "R" is not output in AOS formats. Instead the vi date/time stamp is put here.
2	date/time at end of 1 sec sample, YYMMDDhhmmss.
3	Blue signal sum, signed 32 bit integer in hex.
4	Blue reference sum.
5	Blue samples count, unsigned 12 bit hex integer.
6	Blue ADC overflow flag count, should be zero.
7	Green sig sum.
8	Green ref sum.
9	Green sample count.
10	Green overflow count.
11	Red sig sum.
12	Red ref sum.
13	Red sample count.
14	Red overflow count.
15	Dark sig sum.
16	Dark ref sum.
17	Dark sample count.
18	Dark overflow count.
19	Mass flowmeter output in millivolts, 1 sec avg.
20	Mass flow from field15 in lpm.
21	Hex status flags as in F records.

Comment — This field is the last field in the datastream. It allows operators to enter free-form text from the GUI at any time. Operational notes or disruptions may be entered here.

These data are save 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 datastream can occur.

6.1.2 Mentor Quality Assurance/Quality Controlled Datastream

Mentors provide data that has been processed from the “raw” datastreams. In general, data is delivered in 1-month chunks. 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 ‘psap’
[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 Quality Assurance (QA)/Quality Controlled (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, 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 U.S. Department of Energy/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 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:	Blue Abs – Absorbance coefficient in blue (Mm^-1). This is one of this instrument's primary measurements.
Column 3:	Green Abs – Absorbance coefficient in green (Mm^-1). This is one of this instrument's primary measurements.
Column 4:	Red Abs – Absorbance coefficient in red (Mm^-1). This is one of this instrument's primary measurements.
Column 5:	Blue Transmittance – Transmittance in the blue channel. This value is used to determine the need for filter changes (Tr < 0.7 requires a filter change). This is one of this instrument's ancillary measurements.
Column 6:	Instrument Flow – Calibrated flowrate (slpm) this is one of this instrument's ancillary measurements. It is used to indicate times when the pump is off or the filter is being changed.
Column 7:	Dilution Flow – Calibrated flowrate (sccm) of the dilution MFC. This is one of this instrument's ancillary measurements. It is used to calculate the dilution factor (already included in the reported Absorbance measures).
Column 8:	Impactor State – Taken from the impactor datastream. Values can be 0: none, 1: <1um, 10: <10um. 0, or 'none' indicates the impactor is not in place. Effectively, this is the same as the impactor in the 10 um position. This is one of this instrument's ancillary measurements.

6.2 Data Ordering

PSAP data collected are distributed through the ARM Data Center and are presently updated monthly.

6.3 Data Plots

Figure 4 shows a month of ancillary PSAP measurements. The top frame shows the blue transmittance over time. The dotted lines at Tr = 1 and Tr = 0.7 indicate the proper bounds for operation to minimize multiple scattering and departures from Beer's Law. During episodes of high aerosol burdens, the filter may not always be changed frequently enough. The processing algorithm flags periods when Tr is not within bounds.

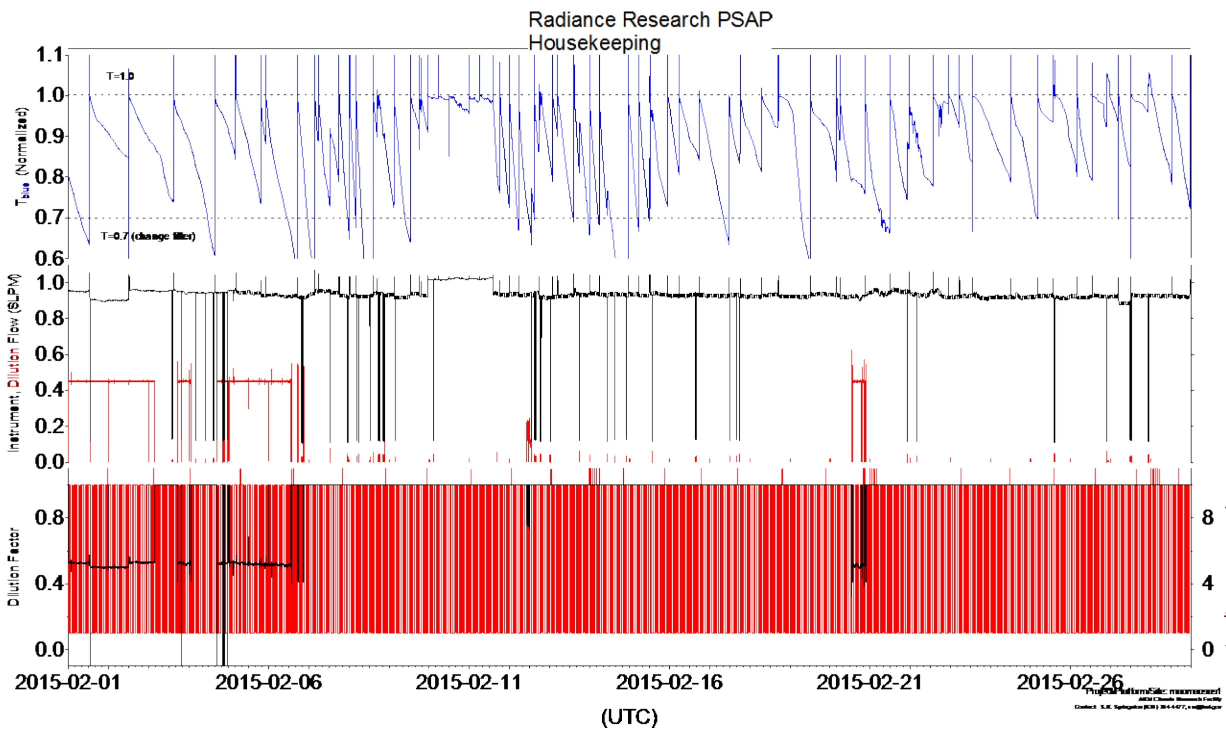

Figure 4. Housekeeping data for 1 month.

The second panel of Figure 4 shows the instrument flow (black trace) and dilution flow (red trace). This month illustrates when things go awry. The instrument flow goes >> 1.0 slpm during filter changes when the filter holder is opened. This allows the periods to be flagged as not valid. It also shows periods when the pump is off, usually due to site power failures. Even though the instrument is backed up with an uninterruptable power supply and the pump comes on once the site generator starts, there are two interruptions to the data: once when power goes down and another when power comes back up. There is roughly a 5-min period around each interruption where the data is flagged as not valid.

The fine structure (not readily apparent in Figure 4) of the instrument flow shows oscillations of ±0.03 slpm indicative of the impactor state. Although the impactor state is separately recorded, this oscillation confirms proper impactor operation. Periods (such as a 2-day interval around 2015-02-11) where the impactor is not operating are readily obvious to the eye, and can be algorithmically flagged.

The red trace in the middle panel of Figure 4 is the flow of dilution. In this month, the source of filtered dilution air (the Pentras Drier) was failing. This is apparent in the gaps of dilution flow. However, as shown in the bottom panel of Figure 4, the dilution factor is automatically determined and is set to 1 (no dilution) if the dilution flow is not functioning.

The red trace in the bottom panel of Figure 4 shows the impactor state. A horizontal blow-up of this panel shows perfect correspondence with the flow changes discussed earlier.

After data quality checks (discussed above), the final data corrected for dilution factor are presented. A typical plot is shown in Figure 5.

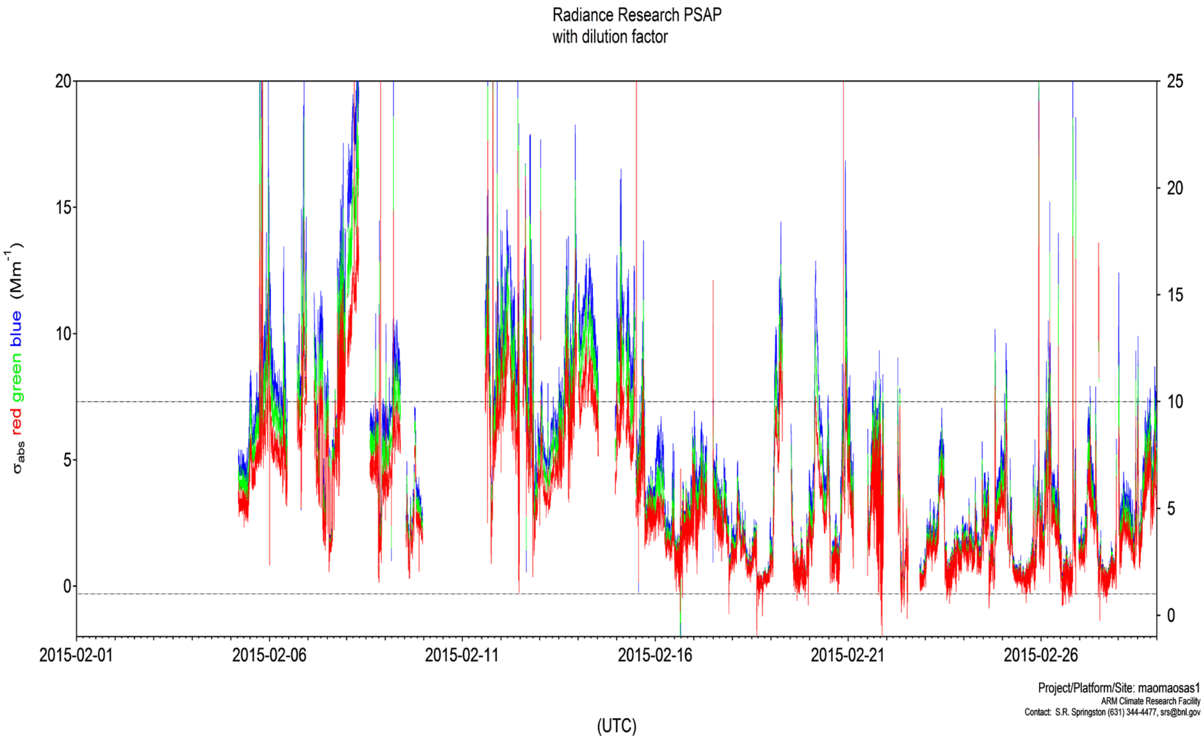

Figure 5. Processed data for 1 month.

6.4 Data Quality

The first level of data quality is automatic flagging of data when transmittance decreases below 0.7, the pumps are off, or the filters are being changed. Most of these events can be identified algorithmically, but not all.

The final level of data quality is inspection of the plots for wild excursions (ringing). These are caused by momentary (~1 s) changes in intensity. It is not clear what causes these excursions. They are obvious in visual inspection, particularly due to the symmetrical nature about zero. They always occur near (just after) filter changes and also accompany power failures and resumptions. The automatic processing has relatively conservative (wide) bands around these events where data is invalid. However, occasionally the excursions are present outside even these wide bands. This can be due to line voltage instability, longer-than-normal filter changes, sudden excursions in the heating or air conditioning, or undocumented temporary changes in the sample inlet. Mentor judgment is exercised in identifying and flagging these periods.

6.5 Calibration Data Base

There is no effective way to calibrate the PSAP using a realistic absorbance standard. Instead, the absorbance of aerosols as measured by the PSAP is considered a first-principles measurement. The instrument and dilution flow rates and the spot size are all calibrated and used in the processing of the resultant data.

Spot size is measured upon receipt of the instrument. Flows are calibrated at the beginning of each deployment and generally at 6-12 month intervals in the field.

Zero checks are not considered appropriate given the nature of the measurement principle. Laboratory exercises involving putting a high-efficiency particulate air (HEPA) filter on the inlet leads to zero response on all three channels.

7.0 Technical Specification

7.1 Units

The measured quantity of interest is the optical absorbance of aerosols. This is reported in units of reciprocal megameters (Mm^{-1}). The instrument measures transmittance as a ratio of intensities between the sample and reference cells. The first derivative of transmittance with time is absorbance. The instrument also reports instrument mass flow. Absorbance is reported at STP (0ºC and 1 atm).

7.2 Range

The full range of this model is somewhat arbitrary. Ambient absorbance of aerosols in non-urban locations generally ranges from 0-50 Mm^{-1}, but can be much higher during biomass burn events or local contamination from the on-site generator.

7.3 Accuracy

The PSAP does not measure absorbance directly. What the PSAP measures is transmittance through an increasingly dirty filter. From the first derivative of transmittance over time, extinction is calculated, which is the sum of absorbance and scattering.

Accuracy of the PSAP is not generally agreed on in the community. Bond et al. discuss some of the many corrections of PSAP data. These corrections involve filter loading and inferring the scattering on the PSAP filter based on co-located nephelometry data, the so-called "Bond Corrections." For aerosols with high single-scattering albedo, the scattering correction can be a sizable fraction of the original PSAP measurement, up to 50%.

In sum, the PSAP measures what the PSAP measures.

7.4 Repeatability

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

Absorbance $\sigma \sim 0.1\ Mm^{-1}$ without dilution for 60-s averaged intensity data.

This is a best case. A factor of 0.5 dilution (dilution air set to 50% of sample inlet flow) increases the standard deviation of the signal by ~2-3 X. The signal measured by instrument is reduced proportional to the dilution and there is additional uncertainty introduced by drift in the calibration of the dilution MFC.

Note that these Confidence Intervals represent repeatability over a relatively short period of time. Day-to-day and month-to-month repeatability has a larger confidence interval.

7.5 Sensitivity

Sensitivity with no dilution is taken as 3 X σ or 0.3 Mm^{-1} for 60-s averaging of intensities.

7.6 Uncertainty

Uncertainty is an integral of all errors. It is a combined measurement of accuracy and precision (repeatability) discussed above. Absent a true reference absorbance measurement, the uncertainty of the PSAP is ill defined.

7.7 Output Values

Described in Section 6.0.

8.0 Instrument System Functional Diagram

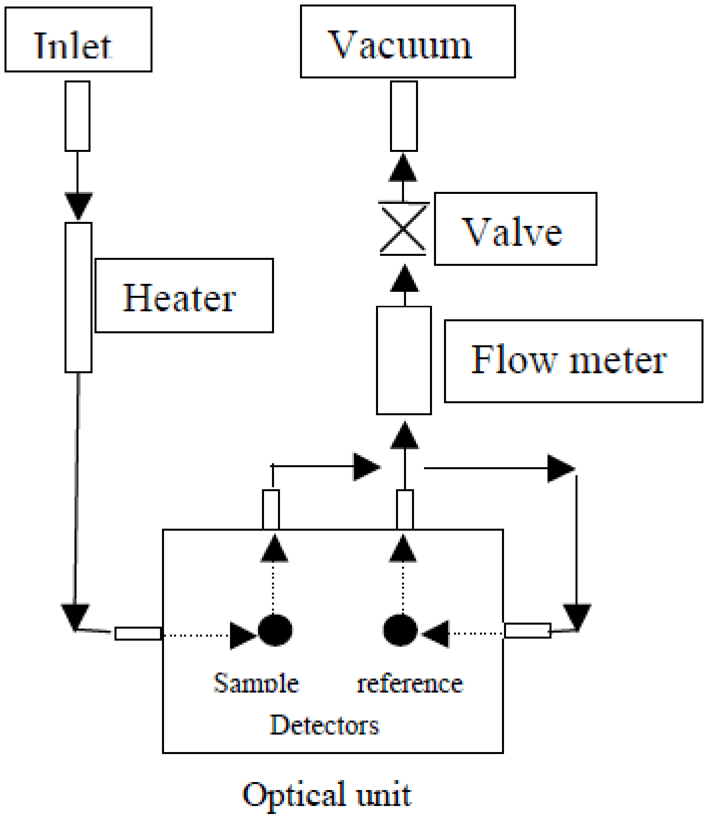

Figure 6. Flow schematic.

Air is sampled from the AOS high-flow aerosol inlet. A 1-/10-µm impactor is now used in all AOS systems. The impactor alternates between the two sampling cutoffs (all particles < 1 µm and all particles < 10 µm). The impactor output is shared between the PSAP, two nephelometers, and where present, the CAPS and PASS-3 systems. The impactor operates on a complicated switching schedule in accordance with other ARM instruments. A PermaPure Nafion drier is used upstream of the PSAP to dry the sample prior to entering the instrument. The PermaPure drier uses the counterflow of the PSAP exhaust at low pressure to dry the sample air. Because of the effectiveness of the drier, the heater shown in the flow schematic is NOT used in AOS sampling.

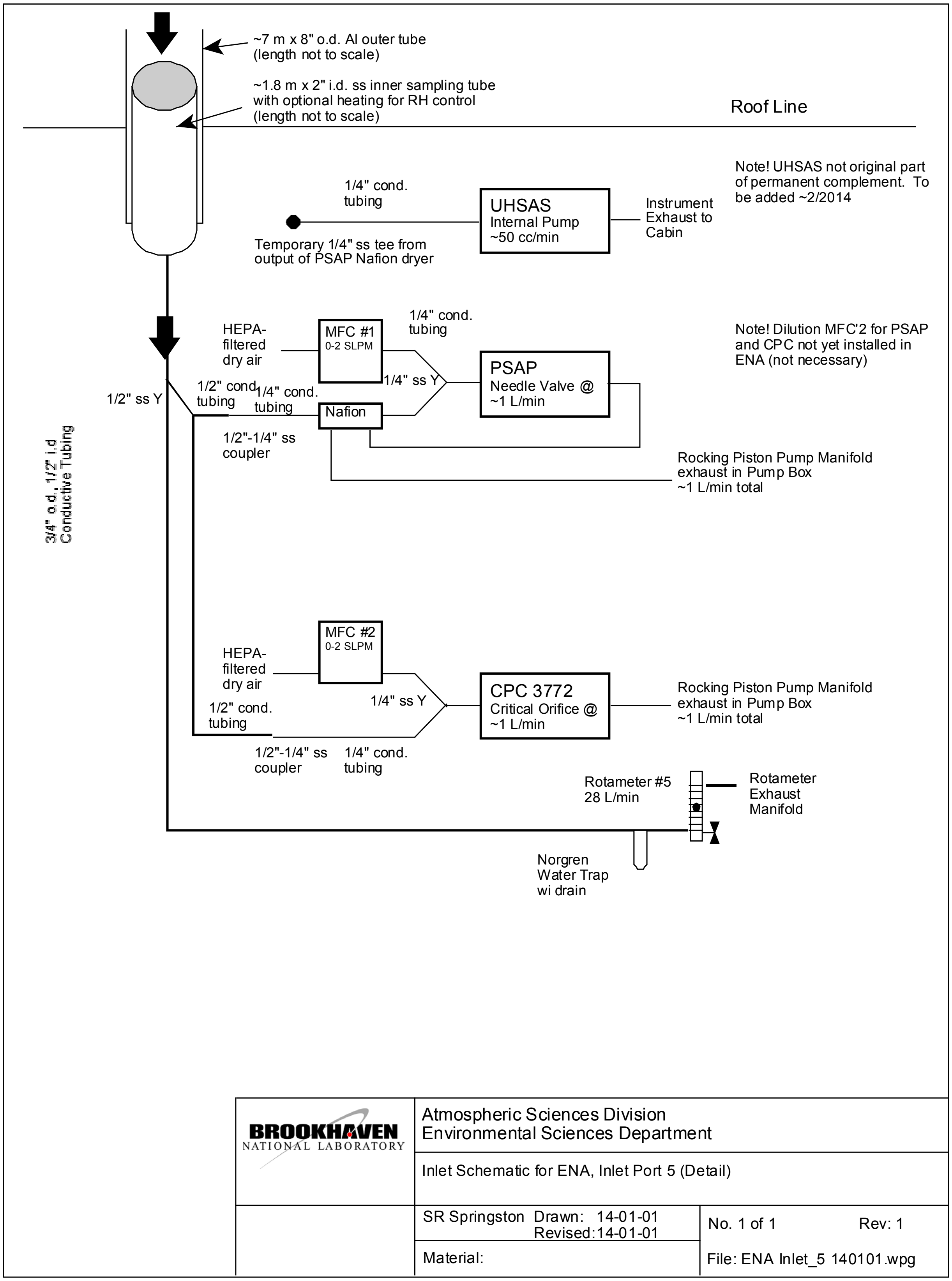

Figure 7. Ground inlet schematic.

9.0 Deployment Locations and History

The following description is taken from the PSAP Manual:

The method is based on measuring the optical transmittance at three wavelengths through a filter as particles are deposited. There are two optical paths: one through the filter with deposited particles, and a second path through a clean filter, used as a reference to determine transmittance, Tr. An experimentally determined transfer function, Fr, is used to correct the transmittance to the actual transmittance of the column of air drawn through the filter.

The absorption coefficient, σ_{ap}, is calculated from Beer's law using Tr, the flow rate and the area of the deposited spot on the filter.

10.0 Setup and Operation of Instrument

Instrument is installed in the AOS systems. This includes:

1. Physical mounting of the instrument in a shock-isolated 19" instrument rack and electrical connection to the appropriate Power Distribution Unit.
2. Plumbing of the sample line into the fast flow ½" Silastic sample manifold line. Prior to the instrument, the sample goes through a 1/10 µm impactor, a Nafion drier, and optional dilution by HEPA-filtered dry air.
3. Setting of front panel settings (date/time are recommended to be set, but are not crucial as data is time stamped by the instrument computer) for file output. The MFM calibration settings, spot size. and Bond Correction coefficients are left in the default state (and the instrument values of these are not used in subsequent processing).
4. Connection of the dilution MFC to the RS-232 connection of the instrument computer.
5. Connection of the PSAP RS-232 output to the instrument computer.
6. Connection of the 110 VAC power line to the appropriate Power Distribution Unit outlet.

After power is turned on, the instrument goes through self-checks and commences putting out data. After extended storage or transportation, the PSAP display occasionally comes up garbled. Reseating of all internal boards is the best remedy for this behavior.

11.0 Software

The instrument uses software in an EPROM version 2.03. This code is in assembly and is not available to users. Except for resetting the optical transmittance to 1.0 and adjusting the nominal flow rate to 1.0 slpm following filter changes, there is little interaction with Operators.

A Graphical User Interface (GUI) has been written by BNL for the instrument computer ("brick") acquiring data from the PSAP Analyzer. This GUI is similar to other AOS instrument GUIs. For the instrument operating with dilution, the flow is controlled in the same vi.

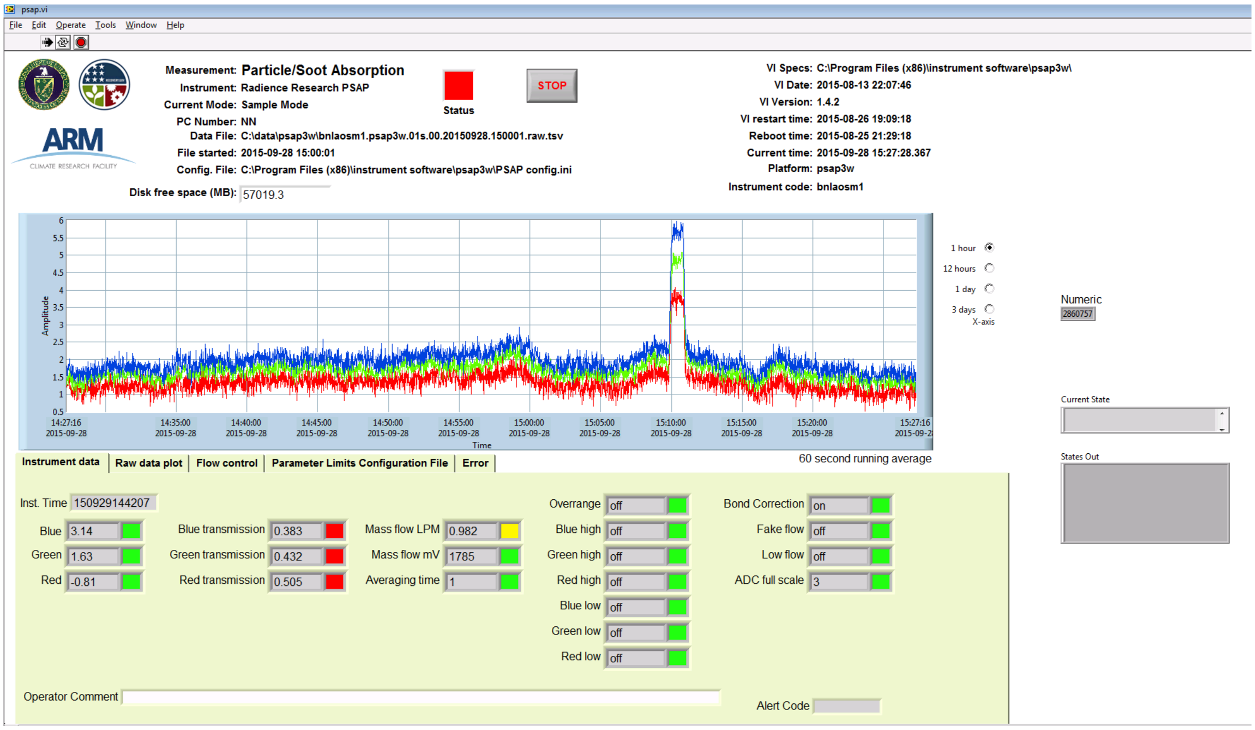

Figure 8. GUI for operator.

The interface has multiple tabs of information. The default plot shows a 1-h, 12-h, 1-day, or 3-day time series plot. A local interference from transportation is evident at 15:10. The instrument parameters are color-coded based on limits contained in a configuration file. In this case transmission is < 0.7 and the flow rate has decreased below 0.98 lpm. The green/yellow/red lights allow the operator to rapidly assess the operating conditions.

A section labeled "Operator Comment" allows free-form notes to be entered into the raw datastream with an accurate time stamp.

12.0 Calibration

Calibration procedures are described earlier. These include an initial measurement of spot size and regular calibrations of instrument and dilution flow rates.

Because the data processing requires knowledge of dilution and instrument MFC 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. Filter changes (sample and reference) are done when the blue transmittance decreases below 0.7. After the filter change, the transmittance is reset to 1.00 and the flow adjusted to a nominal 1.00 slpm. A procedure is given in the AOS Operating Procedures.

14.0 Safety

Unit has no safety concerns during normal operation. Inside the instrument there is a 110 VAC power supply.

15.0 Citable References

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