

DRI STANDARD OPERATING PROCEDURE

Performance Audit of Continuous Ozone Analyzers

DRI SOP #4-101.2

**Desert Research Institute
Division of Atmospheric Sciences
2215 Raggio Parkway
Reno, NV 89512**

(775) 674-7044

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Title: Performance Audit of Continuous Ozone Analyzers

1.0 GENERAL DISCUSSION

1.1 Purpose of Procedure

This standard operating procedure is intended to provide the procedures for conducting a performance audit of the Thermo Environmental Instruments (TEI) Ozone Analyzers, Model 49, operated by Atmospheric Research and Analysis (ARA), Inc. at the Southeastern Aerosol Research Characterization (SEARCH) study sites.

This procedure will be followed by all audit personnel of the Division of Atmospheric Science of the Desert Research Institute.

1.2 Underlying Principles

The TEI Model 49 ozone analyzer uses the ultraviolet absorption technique at a wave length of 254 nm to measure ambient ozone concentrations. One minute averages are collected by the site computer data acquisition system. The ambient sample is collected at a level above the ground of approximately 9 meters at the same location as gases collected by other continuous analyzers.

The performance audit consists of the introduction of zero air and several upscale ozone concentrations to the site analyzer while simultaneously measuring the concentration with an independent Ozone Analyzer using the ultraviolet absorption measurement technique. The audit transfer standard is referenced to DRI's primary ozone standard which is in turn verified with the long-path ozone photometer maintained by the California Air Resources Board in Sacramento, CA. Zero air is generated by passing ambient air through silica gel, Purafil (potassium permanganate and alumina), and activated charcoal to remove ozone and water vapor from the air. Ambient pressure and sample chamber temperature are used to convert the instrumental ozone reading to actual conditions.

1.3 Method Interferences and Their Minimization

Gaseous components or fine particles that absorb or scatter light at 254 nm are potential interferences. The gases in ambient air do not interfere. Particles are removed during the generation of clean air.

1.4 Ranges and Typical Values of Measurements

The ambient ozone concentration ranges from 0 to 150 ppb. The audit ozone concentrations range from 0 to 400 ppb.

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1.5 Typical Lower Quantifiable Limits, Precision, and Accuracy

The accuracy of the audit ozone transfer standard is $\pm 1\%$. The accuracy of the pressure standard is ± 2 mb. The accuracy of the temperature sensor is ± 0.5 °C.

1.6 Audit Criteria

The following set of flags is used to notify the operator of the audit results and the recommended action:

Measurement	CRITERIA/FLAGS (W, R, S)			
	None	Warning	Recalibrate	Suspect
Difference (%)	0-5	$\pm 5-10$	$\pm 10-15$	$> \pm 15$
Slope (deviation from 1.00)	$< \pm 0.05$	$\pm 0.05-0.10$	$\pm 0.10-0.15$	$> \pm 0.15$
Intercept (deviation from zero)	$< \pm 1\%$ full scale	$\pm 1\%-2\%$ full scale	$\pm 2\%-3\%$ full scale	$> \pm 3\%$ full scale

From U.S. EPA (1984): "Quality Assurance Handbook for Air Pollution Measurement Systems: Volume II".

1.7 Personnel Responsibilities

The Field Auditors should read and understand the entire standard operating procedure prior to conducting a performance audit. Familiarity with the operation of the sampling equipment and the audit equipment is necessary for valid measurements. In addition the Field Auditor generates a preliminary report of the audit results at the time of the audit to be presented to the site operator.

It is the responsibility of the Audit Supervisor to ensure the audit procedures are properly followed, to examine and document all documentation, to arrange for maintenance and repair of audit equipment, to maintain the supplies necessary to insure uninterrupted measurements, and to generate a report summarizing the audit results.

1.8 Definitions

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The following terms are used in this document:

Performance audit: Comparison of instrument response to audit standards.
Audit standards: Standards provided by auditor for comparison.

1.9 Related Procedures

- DRI SOP #4-206.1: Calibration of Ozone Transfer Standard
- DRI SOP #4-209.1: Calibration of Pressure Transfer Standard
- DRI SOP #4-210.1: Calibration of Temperature Transfer Standard

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2.0 APPARATUS, INSTRUMENTATION, REAGENTS, AND FORMS

2.1 Apparatus and Instrumentation

2.1.1 Description

Dasibi Ozone Transfer Standard, Model 1003PC, S/N 3678

Zero air system with silica gel, Purafil, and activated charcoal

Audit pressure sensor: Thommen altimeter

Audit temperature sensor: Micronta electronic thermometer with sensor attached to sample tube

Teflon tubing, 1/4 inch diameter, PFA grade 440 or 450

Teflon fittings, 1/4 inch, PFA

2.1.2 Maintenance

Transfer standard is calibrated before the audit.

Transfer standard optical tubes are cleaned when Sample Frequency is less than 42.000

Pumps are replaced when bearings become noisy.

Silica gel is changed when color changes from blue to clear.

Purafil is changed when color changes from purple to brown.

Charcoal is changed once a year.

Containers are inspected for cracks each use.

2.1.3 Spare Parts and Supplies

Silica gel, Fisher Scientific, 750 Laurelwood Rd., Santa Clara, CA 95054

Purafil Chemisorbent Media RP 1/8 in, Air Filter Controls, 585 Charcot Ave, San Jose, CA 95131

Activated charcoal, P/N 05-685B, Fisher Scientific, 750 Laurelwood Rd., Santa Clara, CA 95054


2.2 Forms and Paperwork

Audit forms for the Ozone Analyzer.

Electronic copy of audit form on portable computer that includes computation formulas.

The blank worksheet for the input for the ozone instrument audit is shown in Figure 2-1 and the blank worksheet for result of the ozone instrument audit is shown in Figure 2-2.

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	OZONE INSTRUMENT AUDIT INPUT Dasibi 1003 PC Calibration System	REV 08/01									
Sampling Network: <input type="text" value="SEARCH"/> Auditor: <input type="text"/> Operator: <input type="text" value="ARA"/>	Site Name: <input type="text"/> Site ID: <input type="text"/> AIRS #: <input type="text" value="NA"/>	Date: <input type="text"/> Start Time: <input type="text"/> CST End: <input type="text"/> CST									
Ozone Instrument Information:											
Manufacturer: <input type="text" value="TEI"/> Model No.: <input type="text" value="49"/> Analyzer S/N: <input type="text"/> Equivalency Number: <input type="text" value="EQOA-0880-047"/> Filter: <input type="text"/>	Analyzer Type: <input type="text" value="Photometer"/> Zero Offset: <input type="text" value="1.0"/> Span Slope: <input type="text" value="0"/> Flow Rate: <input type="text"/> lpm Scrubber: <input type="text"/>	Range: <input type="text"/> Fullscale: <input type="text" value="500"/> ppb Correction: <input type="text"/> Slope: <input type="text" value="1.000"/> Intercept: <input type="text" value="0"/>									
Audit Instrument Information:											
Manufacturer: <input type="text" value="Dasibi"/> Model No.: <input type="text" value="1003-PC"/> Analyzer S/N: <input type="text" value="3678"/> Sample Frequency: <input type="text"/> Control Frequency: <input type="text"/>	Analyzer Type: <input type="text" value="Photometer"/> Certification Date: <input type="text" value="Aug 2001"/> Zero Setting: <input type="text" value="0"/> Span Setting: <input type="text" value="48.25"/> Sample Flow: <input type="text" value="2.0"/> lpm	Site Pressure: <input type="text"/> mm HG Cert. Slope: <input type="text"/> Cert. Int.: <input type="text"/> Date: <input type="text"/> Generator Flow: <input type="text"/> lpm									
Audit Results											
Zero-Before O3 Setting: <input type="text"/> Aud Temp: <input type="text"/> deg. C ppb ppb											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
~400 O3 Setting: <input type="text"/> Aud Temp: <input type="text"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
~300 O3 Setting: <input type="text"/> Aud Temp: <input type="text"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
~200 O3 Setting: <input type="text" value="2.30"/> Aud Temp: <input type="text" value="46.6"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
~100 O3 Setting: <input type="text" value="1.65"/> Aud Temp: <input type="text" value="46.6"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
~50 O3 Setting: <input type="text" value="1.40"/> Aud Temp: <input type="text" value="43.4"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
Zero-After O3 Setting: <input type="text" value="0"/> Aud Temp: <input type="text" value="44.7"/> deg. C											
1	2	3	4	5	6	7	8	9	10	Avg	Net
Inst											
Aud											
Comment: _____ _____ _____											

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Figure 2-1: Blank Worksheet for Ozone Instrument Audit Input

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	<h2 style="margin: 0;">OZONE INSTRUMENT AUDIT RECORD</h2> <p style="margin: 0;">Dasibi 1003 PC Calibration System</p>	<p style="margin: 0;">REV 08/01</p>
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Sampling Network: <input type="text" value="SEARCH"/> Calibrator: <input type="text"/> Operator: <input type="text" value="ARA"/>	Site Name: <input type="text"/> Site ID: <input type="text"/> AIRS #: <input type="text" value="NA"/>	Date: <input type="text"/> Start Time: <input type="text"/> CST End: <input type="text"/> CST
---	---	---

Ozone Instrument Information:

Manufacturer: <input type="text" value="TEI"/> Model No.: <input type="text" value="49"/> Analyzer S/N: <input type="text"/> Equivalency Number: <input type="text" value="EQOA-0880-047"/> Filter: <input type="text"/>	Analyzer Type: <input type="text" value="Photometer"/> Zero Offset: <input type="text"/> Span Slope: <input type="text"/> Flowrate: <input type="text"/> lpm Scrubber: <input type="text" value="0"/>	Range: <input type="text"/> Fullscale: <input type="text"/> ppb Correction: <input type="text"/> Slope: <input type="text"/> Intercept: <input type="text"/>
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Audit Instrument Information:

Manufacturer: <input type="text" value="Dasibi"/> Model No.: <input type="text" value="1003-PC"/> Analyzer S/N: <input type="text" value="3678"/> Sample Frequency: <input type="text" value="0"/> Control Frequency: <input type="text" value="0"/>	Analyzer Type: <input type="text" value="Photometer"/> Certification Date: <input type="text" value="Aug 2001"/> Zero Setting: <input type="text" value="0"/> Span Setting: <input type="text" value="48.3"/> Sample Flow: <input type="text" value="2.0"/> lpm	Site Pressure: <input type="text" value="0.0"/> mm HG Cert. Slope: <input type="text" value="0.0000"/> Cert. Int.: <input type="text" value="0.00"/> Generator Flow: <input type="text" value="0.0"/> lpm
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Audit Results

Point	O3 Generator		"X"	"Y"	Deviation
	Setting	Air	Audit	Instrument	
		lpm	Conc ppb	Conc ppb	
Zero-Before					-----
~400					
~300					
~200					
~100					
~50					
Zero-After					-----

Average Deviation	
Standard Deviation	
Slope	
Intercept	
Correlation	

Comment: _____

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Figure 2.2: Blank Worksheet for Ozone Instrument Audit Record

3.0 CALIBRATION STANDARDS

3.1 Preparation, Ranges, and Traceability of Standards

The Dasibi Ozone Transfer Standard, Model 1003PC is calibrated with a Dasibi Ozone Photometer, Model 1008PC, S/N 3776. The Photometer is verified annually with the NIST long-path photometer maintained at the California Air Resources Board in Sacramento, CA.

The Thommen altimeter is checked with a Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables (List, 1951).

The Micronta electronic thermometer is compared to the Fluke thermocouple that is calibrated at approximately 0 and 30 °C in a water bath using a Brooklyn Thermometer (29 – 31 °C) S/N 10772 NIST-traceable.

3.2 Use of Standards

The audit transfer standard is calibrated prior to the field audit. If questions arise as to audit results, the transfer standard is calibrated after the audit.

3.3 Typical Accuracy of Calibration Standards

The accuracy of the ozone transfer standard is $\pm 1\%$. The accuracy of the pressure standard is ± 1 mb. The accuracy of the temperature standard is ± 0.01 °C.

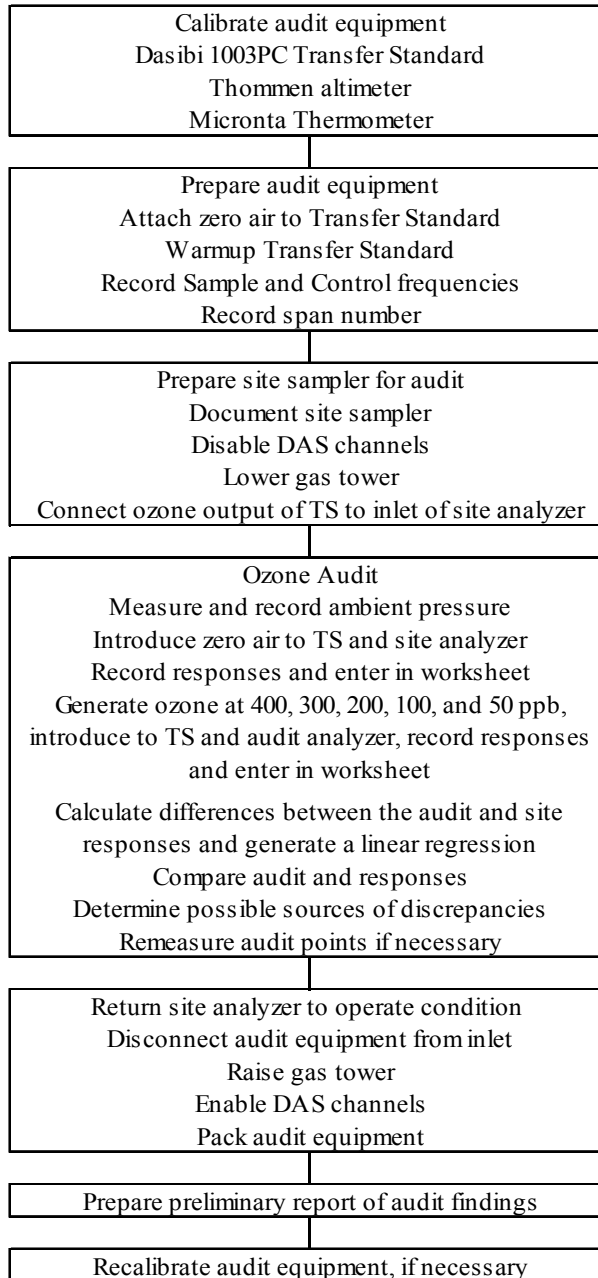
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4.0 PROCEDURES

4.1 General Flow Diagram

The typical flow of the audit procedures for the ozone analyzer is depicted in the following figure.

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4.2 Audit Procedures

The following sections describe in detail the audit procedures for the ozone analyzer. This section must be read and understood in its entirety before beginning audit. It should be reviewed before each audit so that all necessary tasks will be accomplished.

During the audit of the ozone analyzer, audit gas is introduced to the instrument at the instrument inlet. The Audit Transfer Standard (ATS) instrument is operated near the base of the tower under a tent that protects it from direct sunlight and rain. Zero air and ozone concentrations are introduced to the analyzer and to the ATS through Teflon tubing of similar lengths.

4.2.1 Audit Equipment Preparation

- 1) Unpack ATS. Remove zero air canisters, tubing and fittings from Ozone Audit bag.
- 2) Place ATS on small table or box under tent. Remove caps from fittings on rear of ATS. Attach zero air canisters to Air Inlet fitting of ATS so that air entering the ozone generator passes through silica gel, Purafil, and charcoal in that order.
- 3) Connect tubing from Ozone output fitting to inlet to ATS using the tubing that has a Teflon "T" to divert audit gas to the site analyzer. The tubing from the Ozone output fitting to the ATS inlet should be about the same length as the tubing that will connect to the site analyzer inlet.
- 4) Attach power cord to 110 VAC and turn ATS on. Turn ozone and sample pumps on. The sample flow rate, read on the right rotameter, should be about 2 l/min. The ozone flow rate, read on the left rotameter, should be about 5 l/min.
- 5) Allow the ATS to warmup for about 1 hour. The temperature displayed on the thermometer on the front of the ATS will read about 45 °C depending on the ambient temperature when the ATS is ready. The warmup process can be speeded up by placing a piece of paper or a bag on top of the ATS to block the cooling holes. Care has to be taken not to overheat the ATS. Also under very hot ambient conditions, the temperature of the ATS may exceed the 50 °C limit of the thermometer. Under these conditions, the top can be loosed and partially removed to allow more efficient cooling of the instrument. The ATS should be operated at a relatively constant temperature.
- 6) When instrument is warmed up, its zero should be relatively steady and should equal ± 2 ppb. In its normal configuration, a negative concentration on the ATS is denoted by 100.000 – value. e.g., a reading of 99.999 is a concentration of -0.001 ppm or -1 ppb.

- 7) After the ATS has warmed up, switch the mode switch to Samp Freq and Cont Freq to read the Sample and Control frequencies, respectively. The Sample frequency should be in the range of 42.0 to 45.0. The Control frequency should be in the range of 25.0 to 28.0. Frequencies outside these ranges indicate that the sample tubes of the ATS may be dirty and that the position of the ozone lamp is not optimized.
- 8) Check that the span number is 48.25. This span number has been determined from previous calibrations.
- 9) Return mode switch to Sample.

4.2.2 Site Instrument Inspection and Preparation

- 1) Prepare audit forms or audit notebook by entering site name and date of audit.
- 2) Prepare portable computer and Excel Ozone audit worksheet
- 3) Record serial number of instrument.
- 4) Enter pressure on
- 5) When the ATS is warmed up, disable the Gas Analyzer channels on data acquisition system (DAS). Record time that channels were disabled.
- 6) Lower Gas Sample Inlet tower so that the inlet box is near the ground at a level that it can be under the edge of the tent. This protects the inlets to the instruments in case of rain. Move tent over inlet box. Move ATS to near inlet while remaining shaded by the tent. Remove small funnel on inlet to the ozone analyzer. Attach short piece of Teflon tubing to inlet to ozone analyzer. Attach a Teflon "T" to the short tube. Attach the Teflon tube from the ozone outlet of the ATS to one side of the "T". Attach a second short tube to one side of the "T" to prevent air from being pulled back into the "T".

4.2.3 Instrument Audit

- 1) Read and record pressure from Thommen altimeter. Enter pressure on Ozone Instrument Audit Input worksheet.
- 2) With the Ozone Generator switch on the ATS in the Off position, zero air is introduced to the ATS and to the site analyzer. Allow the ATS and site analyzers to reach steady values. The response of the site analyzer will have to be read on the DAS inside the shelter. When the readings have equilibrated, record the time. Read and record 10 updates of the ATS. Each update requires about 25 sec and is indicated by a momentary red light on the front panel. At each update, record the temperature on the thermometer attached to the front of the ATS. After 10 updates, record the time. From the site DAS, record the one-minute average readings that occurred during the 10 ATS readings. There should be about 3 averages during the 10 updates. Enter ATS and site analyzer readings in the Ozone Instrument Audit Input worksheet.

Estimate the average ATS temperature for the readings and enter that value in the worksheet.

- 3) Turn the ATS ozone generator on. Set the switch to Manual. Adjust the pot to 3.90. This should give an ozone concentration of about 400 ppb. Allow the ATS and site analyzer to reach steady values. Following the procedures in step 1), record 10 values for the ATS ozone concentration and temperature and the associated average concentrations for the site analyzer. Enter data in worksheet.
- 4) Repeat steps 1) and 2) at upscale ozone concentrations of approximately 300 (manual setting of 3.00), 200 (manual setting of 2.20), 100 (manual setting of 1.60), and 50 (manual setting of 1.30) ppb. The manual settings for the ozone generator are approximate and may have to be changed if the generated ozone differs by more than 10% from the desired values.
- 5) Repeat step 1) for a final response of the ATS and site analyzer to zero air.
- 6) Review Ozone Instrument Audit Record worksheet for the average deviation of the site instrument from the ATS and their linear regression. If the deviation of any point exceeds 5%, check the values that were entered in the worksheet and correct entry errors. If only one point has a large difference, it should be run again.
- 7) Read pressure again. If pressure has changed by more than ± 2 mb, average starting and ending pressures to obtain pressure for audit.

4.2.4 Return Site Analyzer to Sampling Mode

- 1) Disconnect Teflon tubing from sample inlet. Attach inlet funnel.
- 2) Other analyzers will usually be audited while the tower is down. At the end of gas analyzer auditing or at the end of the day, raise gas sampling tower.
- 3) Enable gas instrument channels on DAS. Record time that the gas analyzers were returned to operational status.

4.2.5 Final Audit Procedures

- 1) Turn power to ATS off. Disconnect tubing from ATS and zero air containers. Pack tubing and containers in Ozone Audit bag.
- 2) Allow ATS to cool to less than 35 °C and pack in shipping box.
- 3) Generate a preliminary report of audit findings that includes the differences between the audit inputs and site analyzer responses. Problems should be identified

5.0 QUANTIFICATION

5.1 Calibration procedures

5.1.1 The Dasibi Ozone Transfer Standard Model 1003PC, S/N 3678, is calibrated with a Dasibi Ozone Photometer, Model 1008PC, S/N 3776.

- 1) Connect air source to zero air containers with the order as silica gel, Purafil, and charcoal with Teflon tubing. Connect tube to outlet of zero air containers and place the other end in an inverted 250 ml bottle. Insert second tube in bottle and connect to ZeroAir Inlet on 1003PC. Insert third tube in bottle and connect to Reference Air Inlet on 1008PC.
- 2) Connect tube from Ozone Outlet of 1003PC outlet to a Teflon "T" and connect tubes from the "T" to the inlets of the 1003PC and the 1008PC.
- 3) Turn on power on 1003PC and 1008PC and allow instruments to warm up for 1 hour.
- 4) After the instruments warm up, record the Sample and Control frequencies and span settings of the 1003PC and 1008PC. Turn on the sample pump, T/P, and valve switches on the 1008PC. Read and record the temperature and pressure.
- 5) Start Excel worksheet for the Ozone Transfer Standard Calibration. Enter instrument information including the frequencies and span values. Enter the certification slope and intercept for the 1008PC, if available. If not, enter 1 for slope and 0 for intercept.
- 6) Turn on 1003PC sample and ozone pump. Leave ozone lamp off. Record ambient pressure and enter in worksheet. Allow 1003PC and 1008PC to stabilize. After readings have equilibrated, read and record 10 updates of the 1003PC. At the time of the update, also read and record the temperature on the thermometer on the 1003PC and the ozone concentration on the 1008PC. Enter 1003PC and 1008PC readings in worksheet. Estimate temperature of 1003PC and enter in worksheet.
- 7) Turn on 1003PC ozone generator and set switch to manual. Turn manual ozone pot to give an ozone concentration of about 450 ppb. After readings have equilibrated, read and record 10 updates of the 1003PC. At the time of the update, also read and record the temperature on the thermometer on the 1003PC and the ozone concentration on the 1008PC. Enter 1003PC and 1008PC readings in worksheet. Estimate temperature of 1003PC and enter in worksheet.
- 8) Repeat step 7) to generate ozone concentrations at 350, 250, 150, and 50 ppb.
- 9) Turn ozone generator off and repeat step 7) for a final zero point.
- 10) Use the work sheet to calculate the pressure and temperature corrected readings for the 1003PC, the differences between the responses of the 1003PC and the 1008PC. Recheck those points that have differences that exceed $\pm 2\%$ for transcription errors. A single point that has a large difference should be run again. The differences are calculated from

$$\%Diff = 100 \left(\frac{C_{1003PC} - C_{1008PC}}{C_{1008PC}} \right)$$

where C_{1003PC} is the concentration response of the 1003PC and
 C_{1008PC} is the concentration response of the 1008PC.

- 11) The worksheet also generates a linear least squares fit using the 1008PC readings as the x variable and the 1003PC readings as the y variable to obtain

$$C_{1003PC} = M C_{1008PC} + B$$

where M and B are the slope and intercept from the least squares fit.

The corrected 1003PC transfer standard is given by

$$C_{1003PC-corr} = \frac{(C_{1003PC} - B)}{M}$$

5.1.2 Thommen altimeter

The Thommen altimeter is checked with a Princo Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables.

- 1) Place altimeter near Princo barometer. Gently tap altimeter and record reading.
- 2) Turn cistern adjustment screw at bottom of Princo barometer until white zero pointer in cistern just touches top of mercury.
- 3) Raise vernier above top of mercury meniscus and lower slowly until the front and back bottom edges of the vernier just appear to touch the top of the meniscus.
- 4) Read the millibar scale indicated by the vernier. The 1's, 10's and 100's places are given by the first line on the scale below the bottom of the vernier. The tenth's digit is given by the line on the vernier that aligns most closely with a scale line.
- 5) Read and record the temperature on the mercury-in-glass thermometer attached to the front of the Princo barometer.
- 6) Repeat steps 1) – 5) three times.
- 7) In Excel spreadsheet, "BARRCORR.XLS", for the next calibration, enter the Princo barometer and temperature readings and the altimeter reading. Duplicate calculations from previous calibrations to determine corrected barometer reading and difference between altimeter and Princo barometer.
- 8) If the altimeter reading differs from the corrected Princo barometer by more than ± 3 mb, the altimeter should be adjusted. There is an adjustment small screw on the back

side of the altimeter behind a small slider. Adjust and recheck against Princo barometer.

- 9) The following corrections are applied to the Princo barometer readings to correct for temperature, latitude, and altitude:

Temperature correction:

$$C_T = p_T - p_R = p_R \left(\frac{1 + L(T - T_S)}{1 + M(T - T_M)} - 1 \right)$$

where C_T is temperature correction,
 p_T is pressure in mb corrected for temperature,
 p_R is barometer pressure reading in mb,
 L is coefficient of expansion for brass scale = 0.0000184 m/m°C,
 T_S is standard temperature for brass expansion = 0 °C,
 M is coefficient of expansion for mercury volume = 0.0001818 m³/m³°C,
 T_M is standard temperature for mercury expansion = 0°C.

Altitude correction for gravity:

$$g_a = g - [3.085462 \times 10^{-4} + 2.27 \times 10^{-7} \cos(2\phi)] Z \\ + [7.254 \times 10^{-11} + 10 \times 10^{-18} \cos(2\phi)] Z^2 \\ - [1.517 \times 10^{-17} + 6 \times 10^{-20} \cos(2\phi)] Z^3$$

where g is gravity at a latitude of 45° and elevation of 0 meters (= 980.616 cm-s⁻²),
 ϕ is latitude, and
 Z is altitude above sea level in meters.

Latitude correction for pressure:

$$C_G = p_L - p_T = p_T \left\{ \frac{g_a}{980.665} [1 - 2.6373 \times 10^{-3} \cos(2\phi) + 5.9 \times 10^{-6} \cos(2\phi)] - 1 \right\}$$

where C_G is correction for latitude,
 p_L is pressure in mb corrected for latitude, altitude, and temperature,
 p_T is pressure in mb corrected for temperature, and
 980.665 is gravity for which correction tables were developed.

Final corrected barometer reading:

$$p_L = p_R + C_T + C_G$$

5.1.3 Micronta Thermometer

A Micronta thermometer is attached to the sample chamber of the Dasibi 1003PC to measure the temperature of the sample chamber. It is checked by putting the Fluke thermocouple probe through the hole in the side of the instrument to contact the sample chamber. The comparison is done several times during the calibration of the Dasibi 1003PC to check the thermometer over a range of approximately 20 °C.

5.2 Calculations

5.2.1 Correction of Dasibi 1003 Ozone Reading to Ambient Temperature and Pressure

The instrumental reading of the Dasibi 1003PC is referenced to 0°C and one atmosphere. The reading needs to be corrected to the pressure and temperature conditions in the sample chamber. The correction of the reading follows from the Ideal Gas Law.

The audit flow meter measures flow rate at ambient conditions while the flow rate through the instrument is maintained at standard conditions (pressure of 1 atm and temperature of 25 °C) by a mass flow controller. The audit flow rates are converted to standard conditions for comparison to the site flows. The conversion of flow rate at ambient condition, Q_{Act} , to flow rate at standard conditions, Q_{Std} , follows the ideal gas law:

$$C_{1003PC-corr} = \left[(C_{1003PC} - Zero) \left(\frac{P_{Std}}{P_{Cham}} \right) \left(\frac{T_{Cham}}{T_{Std}} \right) - B_{Cal} \right] / M_{Cal}$$

where $C_{1003PC-corr}$ is the corrected Dasibi 1003PC concentration,

C_{1003PC} is the reading of the Dasibi 1003PC,

Zero is the average of the initial and final responses to zero air,

P_{Cham} is the pressure in the same sample chamber (~ 4 mb less than ambient pressure) in same units as p_{Std} ,

T_{Cham} is the chamber temperature in °K (°K = °C + 273.15),

p_{Std} is the standard pressure (1 atm, 1013.25 mb, 760 mm Hg),

T_{Std} is the standard temperature, 273.15 °K (0 °C), and

M_{Cal} and B_{Cal} are the regression coefficients for the calibration of the Dasibi 1003PC with the Dasibi 1008 PC.

5.2.2 Differences between Instrument and Audit Measurements

The results of the audit are quantified by comparing the displayed instrument values to the audit measurements for those quantities. The comparison includes the computation of the

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difference and the percent difference between the instrument values and the audit values. The difference and percent differences are computed from the following expressions:

$$\begin{aligned} \text{Difference} &= \text{Instrument} - \text{Audit} \\ \% \text{ Difference} &= \left(\frac{\text{Instrument} - \text{Audit}}{\text{Audit}} \right) 100 \end{aligned}$$

where Instrument represents the value of the audited quantity displayed by the instrument or DAS and

Audit represents the measurement of the audited quantity with the audit equipment.

5.3 Data Acquisition

Data acquisition is done manually by entering audit and site concentrations, pressures, and temperatures on log sheets or in a notebook. The differences between the audit and site responses are calculated in an Excel worksheet and periodically checked by hand. The worksheet also calculates the linear regression between the audit and site concentrations. The regression is also checked by hand.

6.0 QUALITY CONTROL

Quality control is maintained by annual verification of DRI's primary ozone standard with the long-path ozone photometer maintained by the California Air Resources Board in Sacramento, CA. The audit transfer standard is compared to DRI's primary standard before each major audit trip. Calibrations may also be performed following an audit trip if major discrepancies arose between the audit responses and the site instrument responses.

7.0 REFERENCES

List, Robert J. (1951). "Smithsonian Meteorological Tables 6th Revised Edition." Vol. 114, Smithsonian Institution, Washington, DC, 527 pp.