Audit Report of SIMAT Particle Monitoring Network

Performed 21-23 May, 2012

Prepared for: Dirección de Monitoreo Atmosférico, Secretaría del Medio Ambiente del Distrito Federal

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Summary.

An audit of particle samplers at 10 sites in the Sistema de Monitoreo Atmosférico de la Ciudad de México (SIMAT) network was performed on 21-23 May, 2012. Both manual (FRM) and continuous samplers were audited. Audits consisted of flow and leak checks for each sampler as well as review of other relevant operating parameters. At most sites comparisons between audit and site flow standards were also made. Audits were performed on PM monitors at the following sites:

San Juan De Aragón
Tlalnepantla
Xalostoc
Coyoacan
Pedregal
Santa Ursula
Merced
UAM-Iztapalapa
Nezahualcoyotl

PM monitors audited included R&P(Thermo) and BGI FRM manual samplers (9), and Thermo TEOM (7) and BAM (3)continuous samplers – 19 sampler audits total. TEOM samplers included the older model 1400AB PM10 without any sample conditioning, the older 1400AB-FDMS rev-c PM2.5 sampler, and the newer model 1405 dichot FDMS sampler for PM2.5 and PM-coarse.

Audit results are based on the sample flows reported by the sampler, not the flow measured by the site manual flow check, since data are reduced by the data reported by the sampler. A summary of audit results follows; only samplers with audit flow errors > 4% are listed here. Audit criteria used were 4% for warning (corrective action may be needed), and 7% for fail (in bold). For TEOMs, where the sample inlet flow is not the sample sensor flow, a criteria of 10% is used for inlet flow. All flows were measured at local temperature and pressure using a BGI tetraCal flowmeter, factory calibrated 3 April 2012.

FRM:

TLA	R&P Partisol	-4.5%

TEOMs:

XAL	1405DF PM2.5	**10.7%**		
TLA	1405DF PM2.5	5.3 %	PM-coarse	7.0% *****
COY	1400AB/fdms PM2.5	6.0%		
MER	1405DF PM2.5	**7.9%**		

* coarse channel flow error in a dichot sampler does not directly reflect measurement error.

In summary, two samplers failed the flow audit; both were 1405 dichots, the PM2.5 channel. All five of the 3 lpm TEOM sensor flow errors were biased high; this may indicate a common source of error in a site flow standard.

During the audit, other aspects of the network operation were informally reviewed, both at field sites and at the SIMAT laboratory. Overall, the operation of the network is very robust, with strong QA/QC systems in place. Interactions with SIMAT staff indicated a high level of skill and understanding of the network's systems.

Introduction.

Sistema de Monitoreo Atmosférico de la Ciudad de México (SIMAT) requested an external audit of network PM samplers to be performed in the spring of 2012. An external audit is an on-site, independent measurement of sampler flows and related instrument parameters on instruments "as found" – no adjustments. SIMAT supplied a list of sites and samplers to audit over a three-day period; audits were performed 21-23 May 2012, using an audit flowmeter, BGI tetraCal s/n 304, factory calibrated on 3 April 2012.

Unlike audits for gas samplers such as ozone or sulfur dioxide, PM samplers can not be "challenged" with a known standard of the pollutant being measured; it is not practical to generate an aerosol of known concentration at a field site. Thus, only indicators of performance such as flows and leak checks can be audited, and a successful audit does not by itself guarantee that the sampler is producing data of known quality. Ongoing co-location with other samplers is an essential component of a quality program for PM samplers.

SIMAT staff were present for the audits, and performed parallel sampler flow checks on most of the audited samplers. Those measurements are not part of the audit, but can be used as diagnostics when audit results indicate possible problems.

PM sampler flows are nominally controlled at the inlet flow setpoint of 16.67 lpm, and all audit results for FRM and BAM samplers, and TEOM sampler inlet flows are calculated relative to this flow. Sensor flows for TEOM samplers range from 1 to 3 lpm, and are also controlled to their respective design setpoints. Different audit pass/fail tolerances are used depending on the type of sampler and what flow is being measured; some samplers (dichot TEOMs) have as many as four different flows.

Audit result flow errors are calculated as: (sampler flow minus audit flow)/audit flow and expressed as percent difference (%diff). Flow error limits used in this report are as follows:

Pass:	No more than 4%
Warning:	greater than 4 and no more than 7%
Fail:	greater than 7%

There are two exceptions to these audit criteria:

1. Inlet flows for TEOMs. The TEOM sensor flow is a small portion of the inlet flow; the inlet flow determines the particle size cut but inlet flow errors do not directly impact data quality. An audit limit of 10% is used for TEOM inlet flows.

2. TEOM dichotomous (dichot) coarse channel flows. In theory, all the coarse PM in the sample inlet flow is present in the coarse channel (along with 10% of the PM2.5). The dichot "virtual impactor" performance is a function of the ratio of total to minor flows; in this case that is the inlet and coarse channel flow. The design value ratio for the TEOM-DF is 10. To assess

performance of a dichot sampler's coarse channel, the total flow should be within 10% of the design value (16.7 lpm), and the total to minor flow ratio should be within 7% of the design value (10). The flow error of the coarse channel should also be within 10% of the design value (1.67).

Finally, the TEOM samplers have an internal calibration value for the mass detector, K_0. This value was also audited, with a pass/fail tolerance of 2%.

<u>Results.</u>

Detailed results for each sampler are given in table 1 for FRM, 2 for TEOM, and 3 for Beta samplers.

FRM (manual) samplers: all FRM samplers passed the audit. Flow errors for all but 1 sampler, the R&P Partisol at TLA, were less than 4%; at TLA the error was -4.5%. In the context of system QC, it is very important that the FRM samplers be operating properly, since the performance of the automated (FEM) samplers is in part determined by comparison to the FRM sampler data.

TEOM (FEM automated) samplers: Four of the seven TEOM samplers showed audit flows in the warning or fail range for PM2.5:

XAL	1405DF PM2.5	**10.7%**		
TLA	1405DF PM2.5	5.3 %	PM-coarse	7.0% *****
COY	1400AB/fdms PM2.5	6.0%		
MER	1405DF PM2.5	**7.9%**		

All flow errors except for SUR (PM10, -2.2%) were biased high, which may indicate an issue with site flow standards. Sampler flows were also measured with the site flowmeter for all but two of the TEOM sites (SUR and COY); these readings are included in the detailed audit data in table 2.

TEOM K_0 values were all within the 2% limit except for the MER coarse channel, which was -2.4% different than the audit standard. This test was repeated with a different audit K_0 filter with similar results (-2.5%).

Table 1: FRM Manual Sampler Audit Results.

Bold indicates out of audit limits (7%)

Italic means corrective action is needed (4%)

All flows LPM as Qa

Site	Date	Mfg	Model	Serial #	PM size	Audit Flow	Sampler Flow	**Audit % Diff**	s/n site flow meter	Site Flow	Site - Audit Flow	% Diff *	Leak Test Pass/Fail	Leak test pass based on mfg. criteria
XAL	21-May-12	BGI	PQ-200	n/a	2.5	16.14	16.67	-3.28		n/a			Pass	
TLA	21-May-12	R&P	Partisol 2000-H	200FB205360112	2.5	15.95	16.67	*-4.51*		n/a			Pass	
COY	22-May-12	BGI	PQ-200	987	2.5	16.27	16.67	-2.46	158	16.60	0.33	2.03	Pass	
PED	22-May-12	R&P	Partisol 2000-H	200FB205310111	2.5	16.30	16.67	-2.27	158	16.92	0.62	3.80	Pass	
PED	22-May-12	R&P	Partisol 2000-H	200FB205350112	10	16.20	16.67	-2.90	158	16.97	0.77	4.75	Pass	
UIZ	23-May-12	R&P	Partisol 2000-H	200FB205340111	2.5	16.12	16.67	-3.41	158	16.24	0.12	0.74	Pass	Primary Sampler
UIZ	23-May-12	R&P	Partisol 2000-H	200FB206820505	2.5	16.34	16.67	-2.02	158	16.86	0.52	3.18	Pass	Collo Sampler
NEZ	23-May-12	R&P	Partisol 2000-H	200FB205290111	2.5	16.26	16.67	-2.52	158	16.83	0.57	3.51	Pass	
MER	23-May-12	BGI	PQ-200	608	2.5	16.45	16.67	-1.34	158	16.87	0.42	2.55	Pass	

Notes:

* not used for audit results

Table 2: Thermo FDMS-TEOM Continuous Sampler Audit Results.

All flows LPM as Qa

Site	Date	Thermo Model	Serial #	PM size	Audit Inlet flow	Sampler Inlet	* Inlet Audit % diff	Audit Fine channel	Audit Fine/10 sensor	sn158 Site Fine channel	Sampler Fine/10 sensor	Fine/10 sensor **Audit % diff**	Audit Coarse Channel	Sampler Coarse Channel	* Coarse **Audit % diff**	Audit inlet to coarse ratio	Audit ratio % diff
XAL	21-May-12	1405DF	211841011	Dichot	15.80	16.67	5.51	14.11	2.71	2.86	3	**10.70**	1.664	1.67	0.36	9.495	-5.05
TLA	21-May-12	1405DF	211331010	Dichot	15.80	16.67	5.51	14.17	2.85	3.04	3	*5.26*	1.56	1.67	**7.05**	10.13	1.28
COY	22-May-12	1400AB/fdms-c	26337	PM2.5	16.30	16.67	2.27	n/a	2.83	3.00	3	*6.01*	n/a				
SUR	22-May-12	1400AB - 35C	22631	PM10	16.41	16.67	1.58	n/a	1.023		1	-2.25	n/a				
PED	22-May-12	1405DF	204770905	Dichot	16.76	16.67	-0.54	15.08	2.96	3.14	3	1.35	1.617	1.67	3.28	10.36	3.65
UIZ	23-May-12	1405DF	211351010	Dichot	Audit not performed; instrument temp/RH sensors not working												
MER	23-May-12	1405DF	204390903	Dichot	16.35	16.67	1.96	14.59	2.78	2.96	3	**7.91**	1.715	1.67	-2.62	9.534	-4.66

Additional audit checks:

K0 Checks: Audit K0 limit = 2%

Site	Date	Leak Check	Fine/pm10 Channel Audit	Site	%Diff.	Coarse Channel Audit	Site	%Diff.
XAL	21-May-12	Pass	15066.5	15064	0.02	15912	15962	0.3161
TLA	21-May-12	Pass	15253.4	15366	0.73	16025	15976	-0.303
COY	22-May-12	Pass	16217	16538	1.94	n/a		
SUR	22-May-12	Pass	12725	12679	0.36	n/a		
PED	22-May-12	Pass	15824.7	15614	1.35	14489	14320	-1.169
UIZ	23-May-12	n/a	n/a					
MER	23-May-12	Pass	169009	15789	1.40	14593	14249	**-2.354** (repeated with different test K0 filters; result was 2.49%)

Bold indicates out of audit flow for main flow sensor [fine channel in the dichot]

Italic means corrective action is needed (4%)

* Note: For Dichot Coarse Mass Flow Audit Results, the CM flow error is not a direct indicator of CM concentration error; that is a function of total flow and total to coarse flow ratios and PM concentrations.
Also, Inlet flow TEOM audit results have a minimal effect on measurement error; a flow tolerance of 10% is acceptable.

Table 3: Thermo FH62 BAM Continuous Sampler Audit Results.

Bold indicates out of audit limits (7%) All flows LPM as Qa

Italic means corrective action is needed (4%)

Site	Date	Mfg	Model	Serial #	PM size	Audit Flow	Sampler Flow	**Audit % Diff**	Site flow meter s/n	Site Flow	Site - Audit flow	% Diff
SJA	21-May-12	Thermo	FH62	E-1243	2.5	16.12	16.67	-3.41	682	16.83	0.71	4.40
NEZ	23-May-12	Thermo	FH62	471	2.5	16.31	16.67	-2.21	158	16.75	0.44	2.70
IZT	23-May-12	Thermo	FH62	466	10	16.36	16.67	-1.89	158	16.90	0.54	3.30

note: not used for audit results

Other audit observations.

While not technically part of the audit, the following are observations made during the audit that may be useful to SIMAT staff.

Site temperature:
The temperature inside most of the site shelters was 16 to 17 degrees C, too cold for the summer season. The shelter temperature should be higher than the highest expected seasonal hourly dew point temperature, to avoid condensation in sample lines and inside analyzers. For the rainy season, a shelter setpoint of 23 to 25 degrees C is preferable. Sites with FDMS or SES-TEOMs should not exceed 25 C because the TEOM filter temperature is 30 C and could become unstable if shelter temperature became too high.

Other sites, especially those with Thermo FH-62 BAMS, can be run warmer - as high as 28 C (shelter temperature should not exceed 30 C). The Thermo BAM sample heater is not effective (the temperature at the filter is not heated much if at all), and thus there may be humidity interferences on days when the dew point temperature is high. This effect would be minimized by running the shelter as warm as possible during the rainy season.

Flow Standards:
For most audit sites, the site flowmeter was a BGI triCal (s/n 158). The triCal is an earlier version of the tetraCal, with an internal temperature sensor instead of the external sensor on the tetraCal. This means that the triCal can take a long time to equilibrate to changes in temperature – an important part of the flow measurement at ambient conditions (Qa). Given the time constrains in field work, I recommend not using triCal flowmeters for field flow standards; both the tetraCal or deltaCal have external temperature sensors and thus equilibrate to temperature changes much more rapidly.

Even with the external temperature sensor, it is important to keep the flowmeter out of direct sun as much as possible, since that can still cause short-term temperature fluctuations. Care must be taken when working on a roof in mid-day sun – the flowmeter must be left [out of its case] in the shade prior to use long enough to be sure that its temperature is stable. 3 degrees C is 1% flow error, so this is an important factor.

The other recommendation is to either send all flowmeters to BGI for calibration more frequently [at least every 24 months – some flowmeter calibrations were from 2004], or develop a rigorous in-house program based on a pair of reference QA flowmeters where one gets re-calibrated once per year - or more often if the difference between them changes from what it was when they were both just calibrated. For example, take sn980 and sn984 and make them a laboratory QC reference pair; compare them when they arrive after factory calibration, and routinely compare them once/month or such. If the difference shifts by more than say 0.5%, something has changed and you would need a 3rd QC flow standard to decide which of the QA pair changed. That way BGI flow calibrations could only be done when a flowmeter really needs it, or perhaps also every few years, but the SIMAT laboratory would still have documented confidence in flowmeter accuracy.

During the audit, other aspects of the network operation were informally reviewed, both at field sites and at the SIMAT laboratory. Overall, the operation of the network is very robust, with strong QA/QC systems in place. Interactions with SIMAT staff indicated a high level of skill and understanding of the network's systems. A review of data from collocated FRM and continuous PM2.5 FEM monitors showed very good agreement and high correlation; these results are a direct result of the efforts and skills of SIMAT staff.

Appendix: Audit flow standards

Audit Flow and K0 standards:

Flowmeter BGI tetraCal, sn304
Last calibration: April 2012

Site Flow Standards

BGI tetraCal, sn 682	"tetraCal"	external temp sensor
BGI triCal, sn158	"triCal"	internal temp sensor

Audit K0 Teom filters:

#	Date	Mass [g]
CVK3228	11/17/2007	0.11312
CVK3313	2/15/2008	0.11304

Note: site flow standard readings are not used for audit results but are useful for understanding the source of audit flow error

Factory flow certifications for BGI tetraCal s/n 304, 3 April and 1 June 2012 “as found” are included below.

BGI INCORPORATED 58 GUINAN STREET WALTHAM, MA 02451
NIST Traceable Calibration Facility, ISO 9001:2008 Registered

tetraCal

CERTIFICATE OF CALIBRATION - NIST TRACABILITY

(Refer to instruction manual for further details of calibration)

tetraCal Serial Number: 000304 DATE 3-Apr-12
Calibration Operator: Brian DeVoe Jr.

Critical Venturi Flow Meter: Max Uncertainty = 0.346%
Serial Number: 1 *CEESI NVLAP NIST Data File 04BGI151*
Serial Number: 2 *CEESI NVLAP NIST Data File 04BGI152*
Serial Number: 3 *CEESI NVLAP NIST Data File 04BGI153*

Room Temperature : Uncertainty = 0.071% Room Temperature: 21.3 C
Brand: *Ever-Safe* Serial Number: 016076
NIST Traceability No. 516837
tetraCal:
Ambient Temperature (set): 21.3 C
Aux (filter) Temperature (set): C

Barometric Pressure and Absolute Pressure
Vaisala Model PTB330(50-1100) Digital Accuracy: 0.03371%
S/N D1430002
NIST Traceable (Princo Primary Standard Model 453 S/N W12537) Certificate No. P-7485
tetraCal:
Barometric Pressure (set): **752** mm of Hg

Results of Venturi Calibration

Flow Rate (Q) vs. Pressure Drop (ΔP). Where: Q=Lpm, ΔP= Cm of H_2O

No. 1 Q= 5.37046 ΔP ^ 0.52938
No. 2 Q= 1.15749 ΔP ^ 0.52821
No. 3 Q= 0.22041 ΔP ^ 0.53674

Overall Uncertainty: 0.35%

Date Placed In Service________________
(To be filled in by operator upon receipt)

Recommended Recalibration Date ______________________
(12 months from date placed in service)

Revised: March 2012

To Check a Tetra Cal 3-Apr-12 BD
6 - 30.00 Lpm
VER. 3.30P

BP= 752.5 mm of Hg
Room Temp= 21.3 C

Maximum allowable error at any flow rate is .75%.
Serial No. 304

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
176.57	21.1	6.86	6.96	6.94	**-0.26**
425.64	21.1	16.81	17.06	16.95	**-0.62**
693.12	21.1	27.50	27.90	28.1	**0.71**

Average %
-0.06

To Check a Tetra Cal
1.20 - 6.00 Lpm

BP= 752 mm of Hg
Room Temp= 21.6 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
181.5	21.2	2.02	2.06	2.04	**-0.73**
357.2	21.2	4.03	4.09	4.08	**-0.31**
497.0	21.2	5.62	5.71	5.75	**0.65**

Average %
-0.13

To Check a Tetra Cal
0.10 - 1.20 Lpm

BP= 752 mm of Hg
Room Temp= 21.7 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
150.95	21.2	0.262	0.267	0.268	**0.52**
377.51	21.2	0.701	0.712	0.708	**-0.58**
608.09	21.2	1.147	1.166	1.167	**0.12**

Average %
0.02

BGI INCORPORATED 58 GUINAN STREET WALTHAM, MA 02451
NIST Traceable Calibration Facility, ISO 9001:2008 Registered

tetraCal

CERTIFICATE OF CALIBRATION - NIST TRACABILITY

(Refer to instruction manual for further details of calibration)

tetraCal Serial Number: 000304 DATE 1-Jun-12
Calibration Operator: Brian DeVoe Jr.

Critical Venturi Flow Meter: Max Uncertainty = 0.346%
Serial Number: 1 *CEESI NVLAP NIST Data File 04BGI151*
Serial Number: 2 *CEESI NVLAP NIST Data File 04BGI152*
Serial Number: 3 *CEESI NVLAP NIST Data File 04BGI153*

Room Temperature : Uncertainty = 0.071% Room Temperature: 21.5 C
Brand: *Ever-Safe* Serial Number: 016076
NIST Traceability No. 516837
tetraCal:
Ambient Temperature (set): 21.5 C
Aux (filter) Temperature (set): C

Barometric Pressure and Absolute Pressure
Vaisala Model PTB330(50-1100) Digital Accuracy: 0.03371%
S/N D1430002
NIST Traceable (Princo Primary Standard Model 453 S/N W12537) Certificate No. P-7485
tetraCal:
Barometric Pressure (set): **761** mm of Hg

Results of Venturi Calibration

Flow Rate (Q) vs. Pressure Drop (ΔP). Where: Q=Lpm, ΔP= Cm of H_2O

No. 1 Q= 5.23719 ΔP ^ 0.51983
No. 2 Q= 1.14555 ΔP ^ 0.52451
No. 3 Q= 0.21228 ΔP ^ 0.54527

Overall Uncertainty: 0.35%

Date Placed In Service_______________
(To be filled in by operator upon receipt)

Recommended Recalibration Date ______________________
(12 months from date placed in service)

Revised: March 2012

To Check a Tetra Cal 1-Jun-12 BD
6 - 30.00 Lpm
VER. 3.30P BEFORE

BP= 761.5 mm of Hg
Room Temp= 21.2 C

Maximum allowable error at any flow rate is .75%.
Serial No. 304

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
198.67	21.0	7.65	7.66	7.91	**3.21**
416.95	21.0	16.27	16.30	16.95	**3.99**
701.82	21.0	27.51	27.57	29.24	**6.05**

Average %
4.42

To Check a Tetra Cal
1.20 - 6.00 Lpm

BP= 761.5 mm of Hg
Room Temp= 21.2 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
153.0	21.0	1.68	1.68	1.695	**0.92**
332.6	21.0	3.70	3.71	3.74	**0.93**
490.0	21.0	5.47	5.48	5.60	**2.17**

Average %
1.34

To Check a Tetra Cal
0.10 - 1.20 Lpm

BP= 762 mm of Hg
Room Temp= 22 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error
164.54	20.8	0.284	0.286	0.294	**2.94**
369.85	20.8	0.676	0.679	0.685	**0.93**
574.61	20.8	1.066	1.071	1.088	**1.62**

Average %
1.83

To Check a Tetra Cal 1-Jun-12 BD
6 - 30.00 Lpm
VER. 3.36P

BP= 761 mm of Hg
Room Temp= 21.5 C

Maximum allowable error at any flow rate is .75%.
Serial No. **304**

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error	
191.72	20.6	7.37	7.40	7.42	**0.32**	
418.06	20.6	16.30	16.36	16.28	**-0.49**	**Average %**
693.68	20.6	27.17	27.28	27.38	**0.38**	**0.07**

To Check a Tetra Cal
1.20 - 6.00 Lpm

BP= 761.5 mm of Hg
Room Temp= 21.6 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error	
162.1	20.6	1.78	1.78	1.785	**0.17**	
339.2	20.6	3.77	3.78	3.76	**-0.52**	**Average %**
496.7	20.6	5.54	5.56	5.57	**0.24**	**-0.03**

To Check a Tetra Cal
0.10 - 1.20 Lpm

BP= 761.5 mm of Hg
Room Temp= 21.6 C

Reading Abs. P Crit. Vent. mm of Hg	Crit. Vent. TEMP	Q 760/20 Flow Lpm	QA Flow Lpm	QA TriCal Indicated	% Error	
193.69	20.6	0.340	0.341	0.34	**-0.34**	
377.96	20.6	0.691	0.694	0.69	**-0.53**	**Average %**
578.7	20.6	1.074	1.078	1.085	**0.67**	**-0.06**