STATISTICAL QUALITY CONTROL OF THE PEP PM$_{2.5}$ MONITORS

Michael Riggs
Andrew Clayton

Statistical Research Department
Research Triangle Institute
RTP, NC

Quality Control for PEP Monitors

Objective: To develop procedures for assessing the internal consistency of the PEP PM$_{2.5}$ monitors. The PEP monitoring system will be deemed to be internally consistent when the precision and bias of collocated PEP samplers are within prescribed limits.

Bias: The estimated relative difference between collocated monitors must be between -10.0% and + 10.0%.

$$\text{Relative Difference} = \frac{x-y}{0.5(x+y)} \times 100$$

Precision: The CV of collocated monitors must be <10.0%

$$\text{CV} = \sqrt{LMSE} \times 100$$

PEP Data Structures

A. All the PEP samplers within a region are collocated to a single site for a brief period in January-February of each calendar year.

B. Pairs of PEP samplers are collocated at sites within regions at various times during the remainder of the year

Questions of Interest

Question 1. Is there "good" repeatability of monitors within regions, within quarters, during the full collocations (i.e., data structure A)? Criterion for "good" requires that the upper 95% confidence bound on $\sqrt{MSE} \leq 0.10$.

Question 2. Are any of the samplers biased with respect to the other samplers in the full collocations, by region and quarter? Criterion for bias is significance ($\alpha=0.05$) of pairwise Fisher's LSDs associated with regional ANOVA models fit by quarter and a relative difference $\geq 10\%$.

Question 3. Are the regional variances ($\cong$ repeatability) of the monitors in the quarterly full collocations (i.e., data structure A) homogenous, based on Levene's test?

Question 4. Is the paired collocation variability (i.e., data structure B) $\cong$ the variability of the full January collocation, by region? Results were based on a variance-ratio test (i.e., Model 5 F-test).

Question 5. Is the regional repeatability of the paired collocations approximately equal, by quarter, based on Levene's test?

Model 1

Input: Structure A data

ANOVA model fit separately, by region:

$$y_{ij} = m + t_i + b_j + e_{ij}$$

Where: y_{ij} = the observed $PM_{2.5}$ value of the ith PEP sampler at
   time j
   μ = the fixed $PM_{2.5}$ mean of the "population" of PEP
    samplers
   τ_i = a fixed effect due to the ith PEP sampler
   β_j = the random effect of the jth block (sampling time j)
   ε_{ij} = the random error (assumed normal) of the ith
    sampler at time j

Model 1 Analysis of Variance Table

Source of Var.	Mean Square	Comments
Times	MST	Removal of nuisance time effect
Samplers	MSS	Test vs. MSE to determine bias
Residual	MSE	Provides estimate of repeatability if no block x sampler interaction

THE TAU ESTIMATES

REGION	SAMPLER	TAU	STD_ERR	P_VALUE
4	BGI0225	-0.121	0.3902	0.7652
	BGI0203	-0.082	0.3874	0.8392
	BGI0206	-0.074	0.3861	0.8533
	BGI0204	-0.046	0.3861	0.9081
	BGI0205	0.002	0.3981	0.9959
	BGI0182	0.067	0.3902	0.8683
6	BGI0186	-0.039	0.0534	0.4720
	BGI0184	-0.028	0.0534	0.6043
	BGI0183	-0.013	0.0534	0.8082
	BGI0185	-0.003	0.0534	0.9584
	BGI0181	0.027	0.0534	0.6181
	BGI0217	0.050	0.0556	0.3873

PM2.5 REGIONAL VARIANCE COMPONENT ESTIMATES (UNDER MODEL 1)
FOR QUARTERS 1-4 OF 1999

REGION	QTR	DF FOR ESTIMATE	SQRT(MSE) ESTIMATE	95% C.Ls. ON Sqrt(MSE)
1	2	2	0.00247435	(0.0013, 0.0156)
2	1	2	0.02058536	(0.0107, 0.1294)
4	1	7	0.09893446	(0.0654, 0.2013)
	2	5	0.02335429	(0.0146, 0.0573)
	3	8	0.01093853	(0.0074, 0.0210)
	4	4	0.01764223	(0.0106, 0.0507)
5	1	4	0.01979827	(0.0119, 0.0569)
6	1	14	0.04982693	(0.0365, 0.0786)
9	1	4	0.02425331	(0.0145, 0.0697)
10	2	2	0.01586292	(0.0083, 0.0997)

MODEL NO. 1 RESULTS: PAIRWISE DIFFERENCES IN PM2.5 CONCENTRATIONS AMONG COLLOCATED REGION 4 PEP SAMPLERS IN QUARTER 1 [OVERALL F-TEST : F(5,7)=0.7784, P=0.5952]

SAMPLERS COMPARED	AVG. DIFF.	(95% CONFIDENCE INTERVAL)	RELATIVE DIFF. IN CONC. (%)	LSD P-VALUE
BGI0182 - BGI0225	0.1883	(-0.0617, 0.4384)	20.7	0.1181
BGI0182 - BGI0206	0.1412	(-0.0719, 0.3543)	15.2	0.1611
BGI0182 - BGI0203	0.1488	(-0.0845, 0.3821)	16.0	0.1754
BGI0182 - BGI0204	0.1134	(-0.0997, 0.3264)	12.0	0.2488
BGI0205 - BGI0225	0.1233	(-0.2012, 0.4478)	13.1	0.3988
BGI0204 - BGI0225	0.0750	(-0.1381, 0.2881)	7.8	0.4328
BGI0203 - BGI0205	-0.0837	(-0.3730, 0.2056)	-8.7	0.5158
BGI0205 - BGI0206	0.0762	(-0.2065, 0.3589)	7.9	0.5444
BGI0206 - BGI0225	0.0471	(-0.1660, 0.2602)	4.8	0.6172
BGI0182 - BGI0205	0.0650	(-0.2345, 0.3646)	6.7	0.6235
BGI0203 - BGI0204	-0.0354	(-0.2179, 0.1471)	-3.6	0.6604
BGI0204 - BGI0205	-0.0483	(-0.3310, 0.2344)	-4.9	0.6982
BGI0203 - BGI0225	0.0396	(-0.1937, 0.2729)	4.0	0.7003
BGI0204 - BGI0206	0.0279	(-0.1376, 0.1933)	2.8	0.7024
BGI0203 - BGI0206	-0.0075	(-0.1901, 0.1750)	-0.8	0.9249

MODEL NO. 1 RESULTS: PAIRWISE DIFFERENCES IN PM2.5 CONCENTRATIONS AMONG COLLOCATED REGION 6 PEP SAMPLERS IN QUARTER 1
[OVERALL F-TEST : F(5,14)=1.6005, P=0.2239]

SAMPLERS COMPARED	AVG. DIFF.	(95% CONFIDENCE INTERVAL)	RELATIVE DIFF. IN CONC. (%)	LSD P-VALUE
BGI0186 - BGI0217	-0.0891	(-0.1718, -0.0064)	-9.3	0.0366
BGI0184 - BGI0217	-0.0779	(-0.1607, 0.0048)	-8.1	0.0629
BGI0181 - BGI0186	0.0667	(-0.0089, 0.1422)	6.9	0.0793
BGI0183 - BGI0217	-0.0628	(-0.1456, 0.0199)	-6.5	0.1255
BGI0181 - BGI0184	0.0555	(-0.0201, 0.1311)	5.7	0.1375
BGI0185 - BGI0217	-0.0525	(-0.1352, 0.0302)	-5.4	0.1952
BGI0181 - BGI0183	0.0404	(-0.0352, 0.1160)	4.1	0.2706
BGI0185 - BGI0186	0.0366	(-0.0389, 0.1122)	3.7	0.3163
BGI0181 - BGI0185	0.0300	(-0.0455, 0.1056)	3.1	0.4081
BGI0183 - BGI0186	0.0263	(-0.0493, 0.1018)	2.7	0.4685
BGI0184 - BGI0185	-0.0255	(-0.1010, 0.0501)	-2.6	0.4817
BGI0181 - BGI0217	-0.0224	(-0.1051, 0.0603)	-2.3	0.5702
BGI0183 - BGI0184	0.0151	(-0.0605, 0.0907)	1.5	0.6748
BGI0184 - BGI0186	0.0112	(-0.0644, 0.0867)	1.1	0.7563
BGI0183 - BGI0185	-0.0104	(-0.0859, 0.0652)	-1.0	0.7729

Model 2

Determine if the variance in the sampler repeated measures is equal among regions:

$$y_{ijk} = m + r_k + t_{ik} + b_{jk} + e_{ijk}$$

Where:

$y_{ijk} =$ the observed (log-transformed) PM_{25} value of the ith PEP sampler at time j in region k

$\mu =$ the fixed mean PM_{25} of the "population" of PEP samplers

$r_k =$ a fixed effect due to the kth EPA region

$\beta_{jk} =$ the fixed effect of the jth sampling time within region k

$\tau_{ik} =$ the random effect for sampler i, within region k

$\varepsilon_{ijk} =$ the random error (assumed normal) of the ith sampler at time j, in the kth region.

Model 3

When there are no biases, Model 1 may be simplified:

$$y_{hm} = G + P_h + e_{hm}$$

Where: y_{hm} = observed PM$_{2.5}$ value for sampler m at time h
 G = grand mean
 P_h = effect of time h
 W_{hm} = random (residual) effect of sampler and other components of measurement error for sampler m at time h.

Note: residuals from model (3), unlike those from model(1), include any sampler biases that may exist. Model fitting for (3) should be performed for data associated with those samplers thought to have negligible bias. The estimate of repeatability (the residual mean square) obtained here represents a pooling of the sampler and error mean squares from model (1).

Summary of Results of PEDS Jan-Sept., 1999 Analysis

Question 1. Based on the $\sqrt{MSE} \leq 0.10$. criterion, only the following full collocations had poor repeatability:

> Region 2 in Quarter 1
> Region 4 in Quarter 1

Question 2. Based on significant LSD's the following samplers appeared to be out of control:

Region	Qtr.	Samplers	(Pr>F)	Relative Diff.
1	2	210-212	.0034	-1.7% - -6.0%
4	3	182 & 225	.0466	-2.1% - -3.7%

Based on inspection of the tables of pairwise differences, the following samplers look suspicious event though the differences don't all meet the statistical significance criterion:

Region	Qtr.	Samplers	(Pr>F)	Relative Diff.
4	1	182	0.5952	all $\geq 12.0\%$
6	1	217	0.2239	-5.0% - -9.0%

Summary of Results of PEDS Jan-Sept., 1999 Analysis

Question 3. There were only enough data to answer this question for quarters 1 and 2. For those quarters, we conclude that the regional variances are not significantly different, within quarters.

Question 4. Results were based on a variance-ratio test (i.e., Model 5 F-test).

The following variances were judged to be significantly different:

Quarter	Region	Pairs $\sqrt{MSE}$	Jan. $\sqrt{MSE}$	Pr.>F
1	5	0.063	0.029	0.0260
2	5	0.061	0.029	0.0276
4	5	0.948	0.029	<0.0001

Question 5. Is the regional repeatability of the paired collocations approximately equal, by quarter, based on Levene's test? Strictly speaking, the answer is yes; however, the power of the test appears to be unacceptably low. Based on the $\sqrt{MSE}$ of the pairs, it appears that regions 5 and 2 may be different in quarter 4.