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ELECTRONIC SUPPLEMENTARY  
INFORMATIONAssessing PM<sub>10</sub> source reduction in urban agglomerations for air quality complianceVictoria Aleksandropoulou,<sup>\*a</sup> Konstantinos Eleftheriadis,<sup>b</sup> Evangelia Diapouli,<sup>b</sup> Kjetil Torseth<sup>c</sup> and Mihalis Lazaridis<sup>a</sup>

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## Probability density functions

The probability density function of the Lognormal distribution,  $p_l(x_i)$ , with geometric mean concentration  $\mu_g$  and standard  
10 deviation  $\sigma_g$ , is given as:

$$p_l(x_i) = \frac{1}{\sqrt{2\pi} \times x_i \ln \sigma_g} \exp \left[ \frac{(\ln x_i - \ln \mu_g)^2}{2 \times (\ln \sigma_g)^2} \right] \quad (1)$$

where  $x$  is the pollutant concentration. The cumulative distribution function  $F_l(x)$ , i.e. the probability of a variable  $x_i$  being smaller than  $x$ , is given as:

$$15 \quad F_l(x) = P[x_i < x] = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^m e^{-\frac{t^2}{2}} dt = 1 - F_1'(x) \quad (2)$$

where  $F_1'(x)$  is the complementary distribution function, i.e. the probability of a variable  $x_i$  being larger than  $x$ , and  $m$  is calculated as:

$$m = (\ln x - \ln \mu_g) / \ln \sigma_g \quad (3)$$

20 The estimated values of the geometric mean concentration,  $\mu_g$ , and the standard geometric deviation,  $\sigma_g$  are given by ( $N$  is the number of different  $x_i$ ; maximum likelihood method):

$$\mu_g = \exp \left[ \frac{1}{N} \sum_{i=1}^N \ln x_i \right] \quad (4)$$

$$\sigma_g = \exp \left\{ \frac{1}{N} \sum_{i=1}^N (\ln x_i - \ln \mu_g)^2 \right\}^{1/2} \quad (5)$$

25 For the Weibull distribution, the probability density function  $p_w(x_i)$ , with parameters  $\lambda$  and  $\sigma$ , is given as:

$$p_w(x_i) = \frac{\lambda}{\sigma} \left( \frac{x_i}{\sigma} \right)^{\lambda-1} \exp \left[ - \left( \frac{x_i}{\sigma} \right)^\lambda \right] \text{ for } x_i \geq 0, \sigma, \lambda > 0 \quad (6)$$

where  $x$  is the pollutant concentration. The complementary distribution function  $F_w'(x)$ , i.e. the probability of a variable  $x_i$   
30 being larger than  $x$ , is given as:

$$F_w'(x) = P[x_i \geq x] = \exp \left[ - \left( \frac{x_i}{\sigma} \right)^\lambda \right] \quad (7)$$

The parameters  $\lambda$  and  $\sigma$  of the Weibull distribution are estimated by the maximum likelihood method by ( $N$  is the number of different  $x_i$ ):

$$35 \quad \lambda = \left[ \left( \sum_{i=1}^N x_i^\lambda \ln x_i \right) \left( \sum_{i=1}^N x_i^\lambda \right)^{-1} - \frac{1}{N} \sum_{i=1}^N \ln x_i \right]^{-1} \quad (8)$$

$$\sigma = \left( \frac{1}{N} \sum_{i=1}^N x_i^\lambda \right)^{1/\lambda} \quad (9)$$

## Goodness of fit criteria

Mean Bias Error:

$$\text{MBE} = \bar{P} - \bar{O} \quad (10)$$

40 where the  $P$  and  $O$  are the predicted and observed data.

Root Mean Square Error:

$$\text{RMSE} = \left[ \frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2 \right]^{1/2} \quad (11)$$

where  $N$  is the number of observations.

Index of agreement:

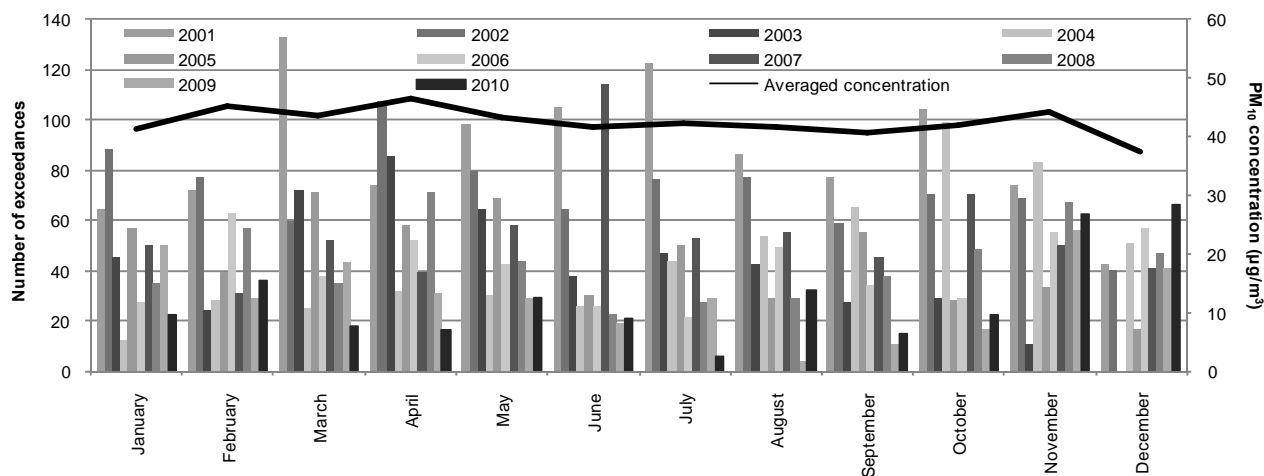
$$45 \quad d = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i - \bar{O}| + |O_i - \bar{O}|)^2} \quad (12)$$

Kolmogorov–Smirnov statistic:

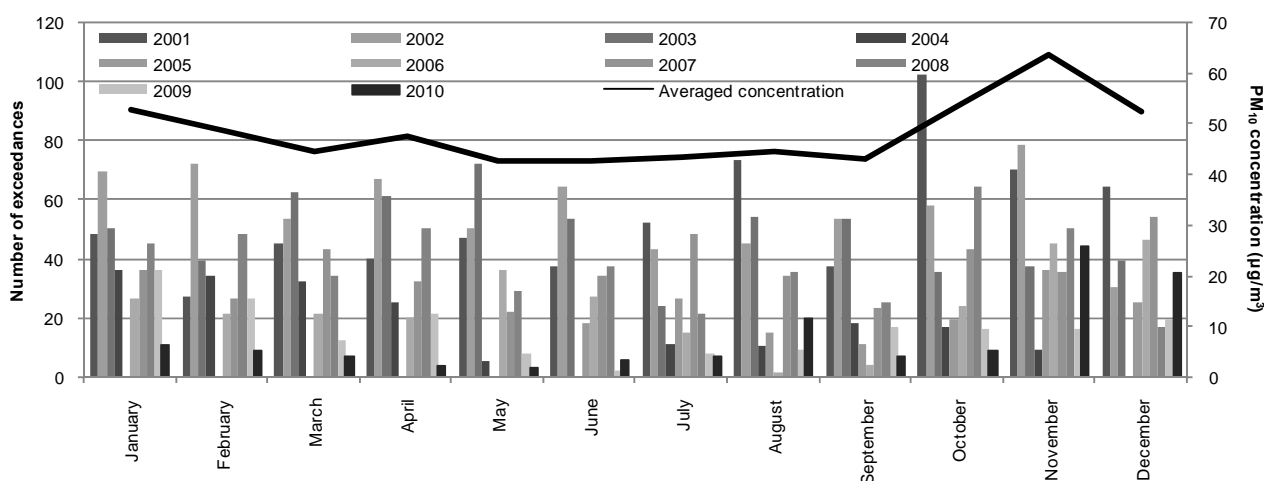
$$D = \sup_x |F_n(x) - F(x)| \quad (13) \quad \text{Anderson-Darling statistic:}$$

where  $N$  is the total number of data points,  $F(x)$  is the theoretical cumulative distribution function (CDF) and  $F_n(x)$  the empirical (observed) one.

$$A^2 = -N - \frac{1}{N} \sum_{i=1}^N (2i-1) \cdot [\ln F(x_i) + \ln(1 - F(x_{N-i+1}))] \quad (14)$$



**Fig. 1** Monthly averaged  $PM_{10}$  concentrations ( $\mu\text{g}/\text{m}^3$ ) and cases (sum of all stations) of non-attainment to AQS at Athens area (2001-2010)



**Fig. 2** Monthly averaged  $PM_{10}$  concentrations ( $\mu\text{g}/\text{m}^3$ ) and cases (sum of all stations) of non-attainment to AQS at Thessaloniki area (2001-2010)

**Table 1** Location and type of  $PM_{10}$  monitoring stations in AMA and TMA along with monitoring periods.

Station	Location	Type	Period
Marousi (TU)	38.03°N, 23.79°E	Traffic Urban	2001-2010
Goudi (TU)	37.98°N, 23.77°E	Traffic Urban	2001-2007 <sup>a</sup>
Zografou (BS)	37.97°N, 23.79°E	Background Suburban	2001-2007
Thrakomakedones (BS)	38.14°N, 23.76°E	Background Suburban	2001-2010
Agia Paraskevi (BS)	37.99°N, 23.82°E	Background Suburban	2001-2010 <sup>b</sup>
Lykovrisi (BS)	38.07°N, 23.78°E	Background Suburban	2001-2010 <sup>b</sup>
Pireaus-1 (TU)	37.94°N, 23.65°E	Traffic Urban	2001-2010 <sup>b</sup>
Koropi (BS)	37.90°N, 23.88°E	Background Suburban	2008-2010
Aristotelous (TU)	37.99°N, 23.73°E	Traffic Urban	2001-2010
Panorama (BS)	40.59°N, 23.03°E	Background Suburban	2001-2009
Kalamaria (TS)	40.58°N, 22.96°E	Traffic Suburban	2007-2010
Agia Sofia (TU)	40.63°N, 22.94°E	Traffic Urban	2001-2010
Kordelio (IU)	40.67°N, 22.89°E	Industrial Urban	2001-2010
Sindos (IU)	40.66°N, 22.80°E	Industrial Urban	2001-2009

<sup>a</sup> Switched to  $PM_{2.5}$  monitoring in 2008; <sup>b</sup> $PM_{2.5}$  monitoring began in 2007.

**Table 2** Goodness of fit criteria for PM<sub>10</sub> distributions.

Station <sup>a</sup>	Period	MBE	RMSE	d	K-S	A-D
Marousi (TU)	2001-2010	-2.5E-06	1.3E-02	0.98	0.072	21.92
Goudi (TU)	2001-2007	-1.6E-04	7.3E-03	0.99	0.045	5.00
Zografou (BS)	2001-2007	-4.4E-10	7.6E-03	0.99	0.033	3.03
Thrakomakedones (BS)	2001-2010	-2.8E-09	8.6E-03	0.99	0.038	5.76
Agia Paraskevi (BS)	2001-2010	-4.5E-09	6.1E-03	0.99	0.041	7.07
Lykovrisi (BS)	2001-2010	-6.2E-08	5.1E-03	~1	0.033	3.24
Pireaus-1 (TU)	2001-2010	-3.2E-06	6.1E-03	0.99	0.025	0.90
Koropi (BS)	2008-2010	8.0E-04	1.1E-02	~1	0.056	4.17
Aristotelous (TU)	2001-2010	-6.9E-10	5.6E-03	~1	0.031	4.07
Panorama (BS)	2001-2009	-1.5E-07	6.6E-03	0.99	0.035	3.16
Kalamaria (TS)	2007-2010	-3.6E-07	8.1E-03	0.99	0.046	1.48
Agia Sofia (TU)	2001-2010	-2.7E-06	3.6E-03	~1	0.025	1.77
Kordelio (IU)	2001-2010	7.2E-04	3.3E-03	~1	0.019	0.48
Sindos (IU)	2001-2009	-3.2E-06	7.1E-03	0.99	0.029	3.27

<sup>a</sup> B: background, I: industrial, T: traffic, U: urban, S: suburban.

**Table 3** Level of PM<sub>10</sub> emissions minimum reduction required for compliance with the 24-h average EU AQ5 and calculated emission change at each monitoring station (different monitoring periods at each station are given in brackets) in the (a) Athens Metropolitan area and (b) Thessaloniki Metropolitan area. Values in brackets correspond to the required emission reduction calculated using 30 µg/m<sup>3</sup> as background PM<sub>10</sub> concentration.

Monitoring Station (Period)	E{C} <sub>s</sub> (µg/m <sup>3</sup> )	Required emission reduction (%) <sup>e</sup>
Aristotelous (2001-2010) <sup>a</sup>	32.44	39.64 (89.72)
Marousi (2001-2010) <sup>a</sup>	28.35	39.37 (109.87)
Pireaus (2001-2010) <sup>a</sup>	30.60	34.75 (96.44)
Lykovrisi (2001-2010) <sup>b</sup>	30.15	44.59 (99.38)
Thrakomakedones (2001-2010) <sup>b</sup>	28.62	5.88 (434.23)
Zografou (2001-2004) <sup>b</sup>	30.28	4.89 (84.94)
Agia Paraskevi (2001-2010) <sup>b</sup>	29.41	14.46 (113.37)
Goudi (2001-2007) <sup>a</sup>	30.13	15.03 (97.55)
Koropi (2008-2010) <sup>b</sup>	28.06	26.31 (124.03)
Agia Sofia (2001-2010) <sup>a</sup>	31.07	44.56 (95.90)
Kordelio (2001-2010) <sup>c</sup>	29.50	49.89 (101.74)
Panorama (2001-2009) <sup>b</sup>	30.69	2.36 (51.74)
Sindos (2001-2009) <sup>c</sup>	31.64	34.45 (91.02)
Kalamaria (2007-2010) <sup>d</sup>	31.04	11.54 (79.51)

<sup>a</sup> Traffic urban; <sup>b</sup> Background suburban; <sup>c</sup> Industrial urban; <sup>d</sup> Traffic suburban; <sup>e</sup> values in brackets correspond to the required emission reduction calculated using 30 µg/m<sup>3</sup> as c<sub>b</sub> in Eq. 15.

**Table 4** Characteristics of the Lognormal distribution ( $\mu$ : geo. mean concentration;  $\sigma_g$ : standard deviation) fitting the PM<sub>10</sub> concentrations and goodness of fit criteria.

Monitoring Station (Period)	Characteristics of PM <sub>10</sub> concentration distribution ( $\mu\text{g}/\text{m}^3$ )						Goodness of fit criteria				
	Observed			Predicted			MBE	RMSE	d	K-S	A-D
Median	St.d.	Min	Max	$\mu$	$\sigma_g$						
<b>(a) Athens Metropolitan Area</b>											
Aristotelous (2005-2010) <sup>a</sup>	48.00	25.46	13.00	421.00	48.56	18.81	3.9E-05	0.009	1	0.041	4.36
Marousi (2005-2010) <sup>a</sup>	42.00	22.64	9.00	331.00	41.85	17.47	-3.2E-04	0.007	1	0.035	2.39
Pireaus (2007-2010) <sup>a</sup>	36.00	19.00	11.00	185.10	35.69	15.45	-3.1E-04	0.003	1	0.022	0.53
Lykovrisi (2001-2008) <sup>b</sup>	53.00	26.90	5.00	438.00	52.93	23.44	-1.02E-03	0.006	1	0.039	4.64
Lykovrisi (2009-2010) <sup>b</sup>	35.10	27.21	8.10	388.00	36.13	16.57	1.4E-03	0.01	1	0.048	2.66
Thrakomakedones (2001-2004) <sup>b</sup>	29.00	19.48	3.40	258.80	28.17	15.01	-3.1E-04	0.008	1	0.037	3.46
Thrakomakedones (2006-2010) <sup>b</sup>	25.00	19.55	2.00	329.00	24.49	13.17	-4.1E-04	0.006	1	0.046	3.11
Zografou (2001-2004) <sup>b</sup>	30.96	17.29	5.25	218.50	30.62	14.26	-1.4E-04	0.005	1	0.031	2.25
Zografou (2005-2007) <sup>b</sup>	25.00	19.02	3.00	387.00	25.64	11.60	-3.2E-04	0.009	1	0.049	3.08
Agia Paraskevi (2001-2005) <sup>b</sup>	34.40	22.22	6.00	198.60	35.40	17.27	1.1E-04	0.006	1	0.029	1.99
Agia Paraskevi (2007-2010) <sup>b</sup>	24.00	17.33	6.00	292.10	24.53	11.29	2.4E-04	0.01	1	0.057	5.43
Goudi (2007) <sup>a</sup>	36.00	15.35	11.00	113.00	35.36	13.55	-4.34E-05	0.014	0.96	0.044	0.74
Koropi (2009-2010) <sup>b</sup>	28.10	25.39	5.00	332.00	29.44	14.00	1.7E-03	0.016	1	0.080	7.18
<b>(b) Thessaloniki Metropolitan Area</b>											
Agia Sofia (2001-2003) <sup>a</sup>	59.98	30.06	14.58	265.25	60.61	25.78	-8.9E-06	0.007	1	0.031	0.86
Agia Sofia (2007-2010) <sup>a</sup>	43.00	21.22	12.00	257.00	43.55	16.80	-1E-03	0.01	1	0.04	1.94
Kordelio (2001-2003) <sup>c</sup>	61.33	30.96	9.92	226.42	60.72	27.80	-7.2E-05	0.005	1	0.024	0.69
Kordelio (2006-2010) <sup>c</sup>	46.00	27.92	9.00	206.00	46.64	23.19	-1.9E-03	0.006	1	0.024	0.56
Panorama (2001-2004) <sup>b</sup>	32.21	15.61	7.50	213.00	31.14	13.56	-1.8E-07	0.007	1	0.033	2.54
Panorama (2006-2007) <sup>b</sup>	26.00	12.06	5.00	91.00	25.46	11.33	-2.1E-05	0.01	0.98	0.065	1.93
Sindos (2001-2004) <sup>c</sup>	45.64	21.47	10.00	211.58	44.82	18.68	-2.2E-04	0.007	1	0.029	1.47
Sindos (2006-2008) <sup>c</sup>	46.00	21.25	11.00	177.00	45.09	18.48	-1.5E-05	0.009	0.98	0.042	1.40
Kalamaria (2007-2008) <sup>d</sup>	36.50	19.09	11.00	142.00	36.58	16.71	-2.2E-03	0.006	1	0.027	0.36
Kalamaria (2009-2010) <sup>d</sup>	31.00	17.39	8.00	206.00	31.75	10.06	-1.4E-03	0.008	1	0.045	0.92

<sup>a</sup> Traffic urban; <sup>b</sup> Background suburban; <sup>c</sup> Industrial urban; <sup>d</sup> Traffic suburban.