COMPARISON OF POPULATION EXPOSURES DURING FOUR SELECTED EPISODE DAYS IN HELSINKI IN 2002

Otto Hänninen [1], Ari Karppinen[2], Jaakko Kukkonen[2], Anu Kousa[3], Päivi Aarnio[3], and Matti Jantunen[1]*

[1] KTL, Dept. Environmental Health, P.O.Box 95, FI-70701 Kuopio, Finland
[2] Finnish Meteorological Institute, Helsinki, Finland
[3] Helsinki Metropolitan Area Council (YTV), Helsinki, Finland

INTRODUCTION

Ambient urban air pollution, especially fine particulate matter ($PM_{2.5}$), has been associated to excess mortality and morbidity at the current urban levels (*WHO*, 2000). Urban air quality is regulated for protection of public health using limit values to which prevailing air quality is compared. Urban populations, however, are mobile and spend their time in different parts of their cities throughout the day, including large fractions of time spent in indoors, where the building modifies air quality (*Koistinen et al*., 2001). A smaller but equally important fraction of time is spent in traffic, where the actual exposures are typically much higher than elsewhere. Therefore in order to evaluate the adverse health effects of air pollution, urban air quality models need to be complemented with modelling of population exposures.

In the current study the FMI urban air quality modelling system for Helsinki was linked with a previously developed probabilistic exposure model. The modelling system was then used to simulate working age population exposure distributions for four selected episode days: spring dust episode (10.4.2002), long-range transport episode (14.4.2002), long-range transport episode with a special contribution for vegetation fires (28.8.2002), and local inversion (22.10.2002). The objectives of the current work are A) evaluation of dispersion and exposure model performance for episodes, B) compare exposure levels during different types of episodes, C) study the relationship of monitored ambient air quality and population exposures, and D) evaluate the health relevance of population exposures in episode situations.

METHODOLOGY

A probabilistic model was previously developed for simulation of population exposures to fine particles (*Hänninen et al*., 2003; *Kruize et al*., 2003; *Hänninen et al*., 2005). The model is based on microenvironment approach. Working age population time activity was classified into five microenvironments for the simulation (residence, workplace (working sub population), other indoor environments, outdoors, and in-traffic (including walking and cycling)). Population time-fraction spent and concentrations in each microenvironment were input as parameters of beta and lognormal probability distributions, respectively.

Dispersion model computations (*Karppinen et al*., 2000a, b) were used to estimate hourly spatial distributions of $PM_{2.5}$ outdoor concentrations during the selected episode days. A stratified random sample of residence and workplace locations was drawn to model spatial variability in population densities between the city areas for different age groups. Lognormal distributions were fitted to the data and used in the simulation.

The indoor $PM_{2.5}$ concentration of ambient origin was calculated using the infiltration factors (*Hänninen et al.*, 2004) and outdoor concentrations as described in more detail in *Hänninen et al.*, 2005. Indoor concentrations were included in a model validation run to compare with corresponding measurements (*Fig. 1*-A). Because the focus of the present work is on ambient air pollution episodes, all exposure levels refer to $PM_{2.5}$ of ambient origin, and in the final models indoor sources were set to zero. Concentrations experienced while in traffic were estimated using measurement data and a state-of-art data analysis (*Jantunen et al.*, 2005).

The dispersion model predictions were compared with monitoring station data. For the whole year of 2002 the daily averages agreed fairly well, but for the episodes the model underestimated levels at fixed monitoring sites in all four cases. For estimation of true exposures, the dispersion model results were corrected by using the fixed monitoring data from Vallila site (*Table 1*). In case of episodes of local origin (spring dust and inversion) it was assumed that the underestimation of concentrations is relative. For long-range episodes it was assumed that adding the Vallila difference corrects all levels.

Table 11. Comparison of predicted and observed levels at Vallila station. Terms used for correction of spatial model data are shown in bold.

Vallila		**a-spring dust** 10.4.2002	**b-LRT** 14.4.2002	**c-LRT/Fire** 28.8.2002	**d-inversion** 22.10.2002
Observed level	$\mu g\ m^{-3}$	27.1	32.0	41.5	24.7
Predicted level	$\mu g\ m^{-3}$	24.6	20.6	20.3	13.0
Ratio obs/pred	1	**1.10**	1.55	2.04	**1.90**
Difference obs-pred	$\mu g\ m^{-3}$	2.5	**11.4**	**21.2**	11.7

The exposure model was compared against personal exposures measured in 1996-97 in the *EXPOLIS* Helsinki -study (*Jantunen et al.*, 1998; *Koistinen et al.*, 2001) for quantification of the model errors. The simulations were executed using the *EXPOLIS* simulation framework (*Hänninen et al.*, 2003; *Kruize et al.*, 2003) with Microsoft (Seattle, WA) Excel version 8.0 and @Risk add-on software version 4.0 (Palisade, Newfield, NY). The selected simulation settings included latin hypercube sampling, 500 iterations and a fixed pseudo-random number seed. Lognormal distribution fits were truncated at 99.9th percentile.

RESULTS AND DISCUSSION

Model performance. Dispersion model underestimated the levels during all episodes (*Table 1*; preliminary evaluation see *Hänninen et al., 2004b*). Therefore additional exposure models were run with corrected input values for estimation of true exposure levels. The exposure model itself was evaluated against previous personal exposure measurements, including estimated indoor sources in the model. The overall match with the observations was good. Model errors (differences between the solid area and line in *Fig. 1*-A) caused by the simplifications in the model were estimated as the relative difference between the bias-corrected observed percentile and the corresponding simulated value. Between the 5th and 95th percentiles the relative model errors varied between –2 and +20 % and absolute errors between –0.3 and 1.3 µgm-3. In the tails of the distribution both the absolute as well as relative errors increase. Especially in the high-end tail the exposure levels are clearly underestimated, indicating relatively rare high personal exposures that are captured with this simple five-microenvironment model. Reasons for underestimated high-end exposures include missing high concentration microenvironments and time spent in proximity of sources, where the general concentration in the current microenvironment is not representative of the exposure level. Some of the underestimated high exposures might be attributable to misclassified exposures to tobacco smoke.

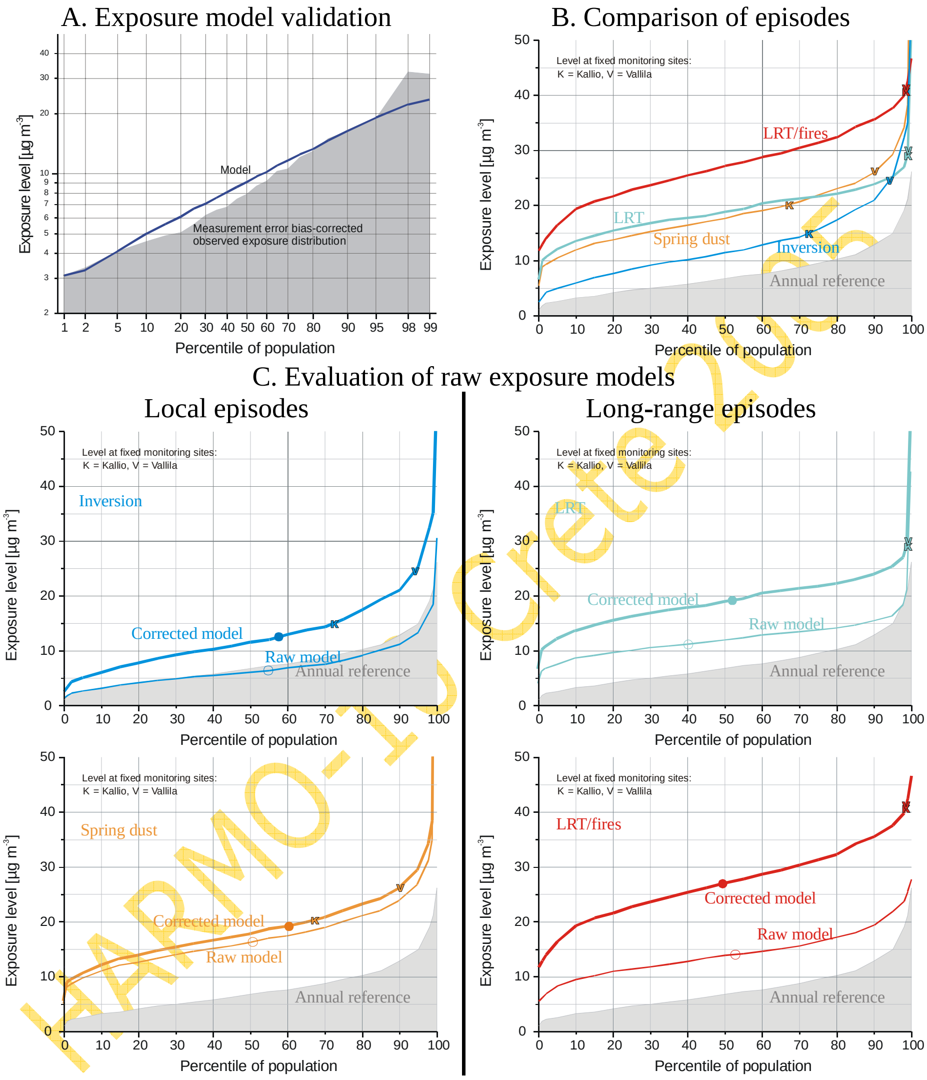

Fig. 23. Exposure results; A. Validation of the exposure model against exposure measurements; B. Comparison of the corrected exposures for the different episodes; C. comparison of raw and corrected models for each episode.

Comparison of exposures during different episodes. Highest exposures occurred during the vegetation fire episode and lowest during the inversion day (*Fig. 1*-B, *Table 2*). The mean exposure level of the former (27 µgm^{-3}) is double compared to the latter (13 µgm^{-3}). The spring episodes from local dust and long-range transport are very close to each other. The local inversion episode captured in this study does not represent a worst case, but worse inversions are rare. In contrast, long-range episodes occurred during the study year several times and are known to be common. In this sense the current results emphasize the role of long-range transported particles in formation of population exposures.

Table 12. Evaluation of the simulation model performance and mean exposure levels.

	Episode							
Exposures and concentrations	**Spring dust**		**LRT**		**LRT/fires**		**Local inversion**	
	10.4.2002		14.4.2002		28.8.2002		22.10.2002	
	mean ± sd		mean	sd	mean	sd	mean	sd
	[µg m^{-3}]		[µg m^{-3}]	[µg m^{-3}]	[µg m^{-3}]	[µg m^{-3}]	[µg m^{-3}]	[µg m^{-3}]
SIMULATION								
Raw dispersion model based exposure	17.1 ± 6.4		12.0 ± 3.2		14.3 ± 4.0		6.8 ± 3.6	
Corrected exposure[1]	18.8 ± 7.0		19.0 ± 4.4		27.2 ± 6.4		13.0 ± 6.8	
Raw model exposure error	**-1.7**	-0.6	**-6.9**	-1.2	**-12.9**	-2.4	**-6.1**	-3.2
Relative error %	**-9 %**	-9 %	**-37 %**	-28 %	**-48 %**	-37 %	**-47 %**	-47 %

Monitored air quality compared with exposures. Comparing daily average concentrations observed at the two available fixed monitoring sites (Kallio and Vallila; symbols K and V in *Fig. 1*-B and C), it is evident that during the LRT episodes both monitored ambient levels represent high exposure percentiles. On the other hand, for the episodes of local origin, spring dust and inversion, the Kallio station level is close to 67th and 73rd percentiles and the Vallila level close to 90th and 95th percentiles, respectively. The Kallio level is quite close to the mean (108% and 113% for the spring dust and inversion episodes, respectively). During the LRT episodes the fixed station levels are close to each other, as can be expected, and both overestimate the mean exposure level approximately 1.5 fold. Moderately traffic oriented Vallila station overestimates mean population exposures during all episodes.

Exposure levels and their health relevance. Exposure distributions for all episodes were significantly higher than the annual reference distribution (1996-7 exposure from the validation model without indoor sources; *Fig. 1*-B). Mean exposure level during the vegetation fire originating long-range transportation episode was three times higher than the annual reference. According to the current understanding, the health effects are caused primarily by accumulating long-term exposures and only secondarily by short-term (i.e daily) exposures; the exposure-response factor for $PM_{2.5}$ for the former is about an order of magnitude higher than for the latter (*WHO,* 2000). Short-term exposures are, however, very relevant for the currently developing EU legislation requiring regulatory actions in case of episodes. Exposure and health research is needed for optimized use of resources and maximal health benefits.

CONCLUSIONS

Environmental policies should ultimately target at improved public health while minimizing non-productive intervention and cost. This can be achieved by optimization of air quality management decisions according to the quantitative estimates of exposures and health risks in scenarios for alternative policy options. Using exposure models in an episode situation makes it possible to compare exposure reduction schemes in terms of efficiency and other local considerations for optimal decisions, including limitations for e.g. private car traffic or local industrial activities.

The same models are valuable in long-term scale. Population exposures can be estimated for e.g. alternative traffic system scenarios, as is done in Helsinki as part of the metropolitan area transportation system plan. The modelling tools can be used to apportion exposures to sources, including the long-range transported pollution, and thus to support setting priorities for local, regional, and international emission control activities.

ACKNOWLEDGEMENTS

This work has been supported by EU Contracts EVK4-CT-2002-00097 (FUMAPEX) and N ENV4-CT96-0202 (*EXPOLIS*; DG12-DTEE), Academy of Finland Contracts 36586, 40835 and 42610, and intramural funding by KTL.

REFERENCES

Hänninen, O.O., Kruize, H., Lebret, E., Jantunen, M., 2003: *EXPOLIS* simulation model: $PM_{2.5}$ application and comparison with measurements in Helsinki. *Journal of Exposure Analysis and Environmental Epidemiology* **13**: 74-85.

Hänninen, O.O., Lebret, E., Ilacqua, V., Katsouyanni, K., Künzli, N., Srám, R.J., Jantunen, M.J., 2004: Infiltration of ambient $PM_{2.5}$ and levels of indoor generated non-ETS $PM_{2.5}$ in residences of four European cities. *Atmospheric Environment* **38**(37): 6411-6423.

Hänninen, O., Karppinen, A., Valkama, I., Kauhaniemi, M., Kousa, A., Aarnio, P., and Jantunen, M., 2004b: Numerical population exposure results in case of peak pollution episodes in Helsinki. FUMAPEX Deliverable D7.3, 30.10.2004.

Hänninen, O.O., Lebret, E., Tuomisto, J.T., Jantunen, M.J., 2005: Characterization of model error in the simulation of $PM_{2.5}$ exposure distributions of the working age population in Helsinki, Finland. *Journal of the Air & Waste Management Association* **55**:446–457.

Jantunen, M.J., Hänninen, O., Katsouyanni, K., Knöppel, H., Künzli, N., Lebret, E., Maroni, M., Saarela, K., Srám, R. & Zmirou, D., 1998: Air pollution exposure in European cities: the *EXPOLIS*-study. *Journal of Exposure Analysis and Environmental Epidemiology* **8**(4): 495-518.

Jantunen, M., Hänninen, O., Ilacqua, V., Karppinen, A., Kukkonen, J., and Aarnio, P., 2005: Exposure levels to exhaust-generated and total $PM_{2.5}$ in traffic. Proceedings of the *5th International Conference on Urban Air Quality*. Valencia, Spain, 29.-31. March, 2005.

Karppinen, A, Kukkonen, J., Elolähde, T., Konttinen, M., Koskentalo, T. and. Rantakrans, E., 2000a: A modelling system for predicting urban air pollution, Model description and applications in the Helsinki metropolitan area, *Atmospheric Environment* **34**: 3723-3733.

Karppinen, A, Kukkonen, J., Elolähde, T., Konttinen, M. and Koskentalo, T., 2000b: A modelling system for predicting urban air pollution, Comparison of model predictions with the data of an urban measurement network, *Atmospheric Environment* **34**: 3735-3743.

Koistinen, K.J., Hänninen, O.O., Rotko, T., Edwards, R.D., Moschandreas, D., Jantunen, M.J., 2001: Behavioral and environmental determinants of personal exposures to $PM_{2.5}$ in *EXPOLIS*-Helsinki, Finland. *Atmospheric Environment* **35**(14): 2473-2481.

Kruize, H., Hänninen, O.O., Breugelmans, O., Lebret, E., Jantunen, M., 2003: Description and demonstration of the *EXPOLIS* simulation model: Two examples of modelling population exposure to particulate matter. *Journal of Exposure Analysis and Environmental Epidemiology* **13**(2): 87-99.

WHO, 2000: Air Quality Guidelines for Europe. WHO Regional Publications, European Series No. 91.