H14-269
EXPOSURE MAPS FOR TWO MEGACITIES WITHIN THE MEGAPOLI PROJECT

Joana Soares[1], Ari Karppinen[1], Jaakko Kukkonen[1], Bruce Denby[2], Sandro Finard[3], Massimo Cassiani[3] and Paula Radice[3]

[1]Finnish Meteorological Institute, Department of Air Quality, Finland
[2] Norwegian Institute for Air Research, Department of Urban Environment and Industry, Norway
[3] National Agency for New Technologies, Energy and Sustainable Economic Development, Italy

Abstract: We present exposure modelling results for two different MEGAPOLI case studies: Greater London (United Kingdom) and Po Valley region (Italy). The methodology described and implemented here illustrates a simple assessment of human exposure for these study areas, i.e. long term exposure at home residences. The present study results are compared with the results from Denby *et al* (2011). The present study only provides an order of magnitude of the values for population averaged concentrations, since these two studies were conducted for different years. The population averaged concentrations obtained from the high resolution exposure study for the Greater London is 24.5 μg/m^3 for PM_{10} and 42.4 μg/m^3 for NO_2. When comparing with the regional scale resolution assessment, the difference in population weighted concentration estimates (and exposures) are 1.5-2 times higher in the high resolution study. This difference can be explained by the different reference years for each study and that the Greater London is represented as a single grid cell in the regional scale resolution study. For the Po Valley region case, the values obtained by these two different modeling studies for PM_{10} are much closer to each other: according to the higher resolution exposure study the population averaged concentrations for PM_{10} are 27.1 μg/m^3 while the values regional scale study range between 16.5-19.3 μg/m^3 in the regional modeling based study. The results for Po Valley are much more comparable since the years studied are much closer - the emissions will be more similar - and the gridding for Po Valley study for the regional scale calculations is much more representative for the whole area than in the Greater London case study.

Key words: *human exposure modelling, MEGAPOLI*

INTRODUCTION

Assessment of human exposure to air pollution is an essential part of environmental risk studies and can be estimated by mathematical modeling. The mathematical modeling is based on deterministic simulation of environmental processes and the assessment of exposure usually requires application of integrated model chain starting from estimation of emissions to atmospheric dispersion and transformation of air pollutants. The exposure model then combines ambient air concentrations of pollutants and population activity data to calculate human personal exposure concentrations or simply ambient air concentrations and population distribution to obtain a proxy for the population exposure. The latter approach was used to determine the exposure to different atmospheric pollutants for computed for two megacities studied by the MEGAPOLI project: Greater London, United Kingdom, and Po Valley region, Italy.Here we present the population exposure to PM_{10} and $PM_{2.5}$.These two cases were chosen based on the availability of concentration and population gridded data. In the following sections modelling tools and data will be described, followed by the results and discussion of the outcome and conclusion.

DATA AND MODELLING TOOLS

To estimate the overall exposure of the population to a certain pollutant, the exposure is modelled by combining concentration and population in a certain period of time. The following equation shows how the exposure (E) is computed for this study:

$$E = n * t * C \tag{1}$$

where n is the number of people per grid cell, t is the time period [s] and C is concentration [μg/m^3] for the pollutant. The final results will be shown as annual average exposures.

The population and concentration data for Greater London was provided by Cambridge Environmental Research Consultants (CERC). Both data sets were provided in a regular grid of points with a resolution of 1*1 km^2 for population data and 50*50 m^2 for concentration data. Population data is based upon a number of spatially resolved datasets derived from an inter-censual data source that can provide estimates for the population stock. To estimate the concentrations CERC utilized the dispersion model ADMS-Urban (CERC, 2001), computing the concentrations for different pollutants such as NO_2 and fine and coarse PM, the compounds of interest for the research undertaken in MEGAPOLI. The base year for the computations is 2001.

The data for the Po Valley Region was provided by the National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Italy. For this case study concentrations were available for several different years (not for 2001). We have chosen the year 2005 for the estimation of exposure for $PM_{2.5}$ and PM_{10} in the Po Valley region. Yearly average gridded data in terms of concentration was obtained with a spatial resolution of 4*4 km^2 and the population data obtained from the municipal census with 1*1 km^{2}resolution. The simulations for the concentrations were carried out with the Atmospheric Modelling System (AMS), which is part of the Italian Integrated Assessment Modelling System for supporting the International Negotiation Process on Air Pollution and assessing Air Quality Policies at national/local level (MINNI) (Zanini et al., 2005).

Some input data was pre-processed for the exposure calculations. Due to the different resolution of the two databases, population data was interpolated to the same grid resolution as concentration data since population data is varying less in terms of magnitude than concentrations. In the case of Greater London data, the population data was interpolated to the same resolution as the concentration data by Aikman's interpolation. This method is a smooth bivariate interpolant suitable for scattered data. Exposure results were plotted with a GIS-based program, MapInfo v8.5.

RESULTS

The human exposure was determined for NO_2, $PM_{2.5}$ and PM_{10}, for Greater London, year 2001; and $PM_{2.5}$ and $PM_{10}$for the Po Valley region, year 2005. The total population for the Greater London is 8.5 million inhabitants. The computational domain for the Greater London is divided in 1297474 grid squares for PM2.5 and 986400 grid squares for PM_{10} and NO_2 of 50 m spatial resolution. Therefore $PM_{2.5}$ exposure calculations include the whole population and PM_{10} exposure calculation includes only 8 million inhabitants. The total population of the Po Valley region is 29 million inhabitants

The annual average exposure in the Greater London to $PM_{2.5}$ for 2001, averaged over all grid squares, is $3.5*10^9$ µg.s/m^3, $6.3*10^9$ µg s/m^3 for PM_{10} and $1.1*10^{10}$ µg.s/m^3 for NO_2. The highest exposure values obtained for the Greater London area grid cells are $3.9*10^{10}$ µg.s/m^3 for $PM_{2.5}$ and $6.5*10^{10}$ µg s/m^3 for PM_{10}. The total exposure for the Greater London is $4.5*10^{15}$ µg.s/m3 for $PM_{2.5}$, $6.3*10^{15}$ µg.s/m3 for PM_{10} and $1.1*10^{16}$ µg.s/m3 for NO_2. The exposure values are relatively higher in the center of the Greater London, decreasing three orders of magnitude for all the pollutants, when focusing on areas closer to the limits of the domain.

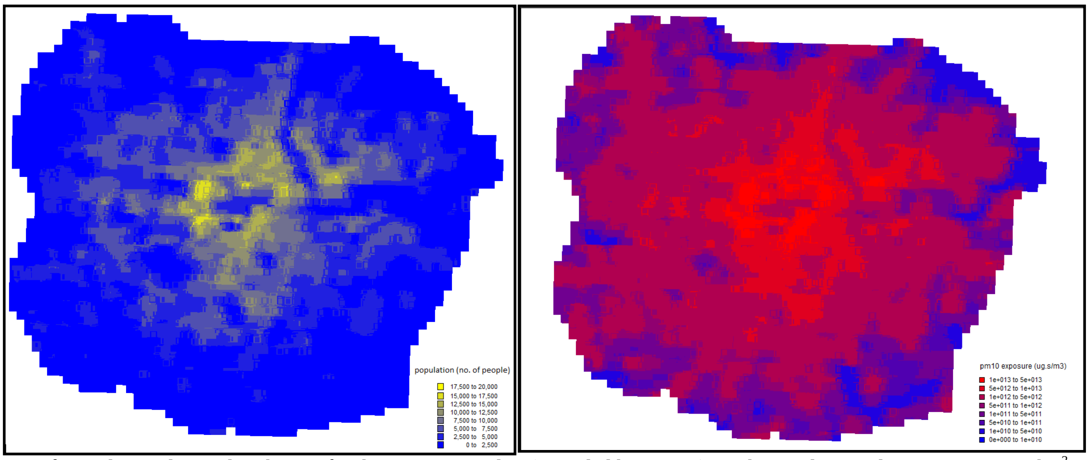

Figure 1. Left panel: population distribution for the Greater London (provided by CERC). Right panel: annual PM_{10} exposure *1 km² grid cell* (µg.s/m^3) for the Greater London, 2001.

For the Po Valley area, the annual average exposures for $PM_{2.5}$ and PM_{10}, for the year 2005 averaged over all grid squares,were $1.6*10^{12}$ µg.s/m^3 and $1.8*10^{12}$, µg.s/m^3, respectively. The exposure is higher for the grid cells (4*4 km^2) including the urban centers of the region, clearly seen in the population map described by Figure 2 - right panel, reaching $5.9*10^{14}$ µg.s/m^3 and $6.7*10^{14}$ µg.s/m^3 for $PM_{2.5}$ and PM_{10}, respectively (note the scaling with the grid cell size). Additionally, higher exposures are seen for the grids cells over the Alps, at the north of the Po Valley Region. The difference from urban to rural areas can be as high as 3 orders of magnitude. The total exposure for all the Po Valley grid squares is $2.2*10^{16}$ µg.s/m^3 for $PM_{2.5}$ and $2.4*10^{16}$ µg.s/m^{3}for PM_{10}.

The presence of areas with zero exposure value can be attributed to the procedure adopted to obtain gridded population from municipal census data. Within every municipality population has been distributed over the target grid using CORINE land cover 2000 "urban" classes space statistics as proxy. The procedure produced cells with 0% urbanisation where no inhabitants have been allocated. This result is a partial artefact (areas over 1 square kilometer with no inhabitants are frequent over the mountains but not over the plains) that can indirectly take into account the commuting of population towards urban centers during daytime working hours.

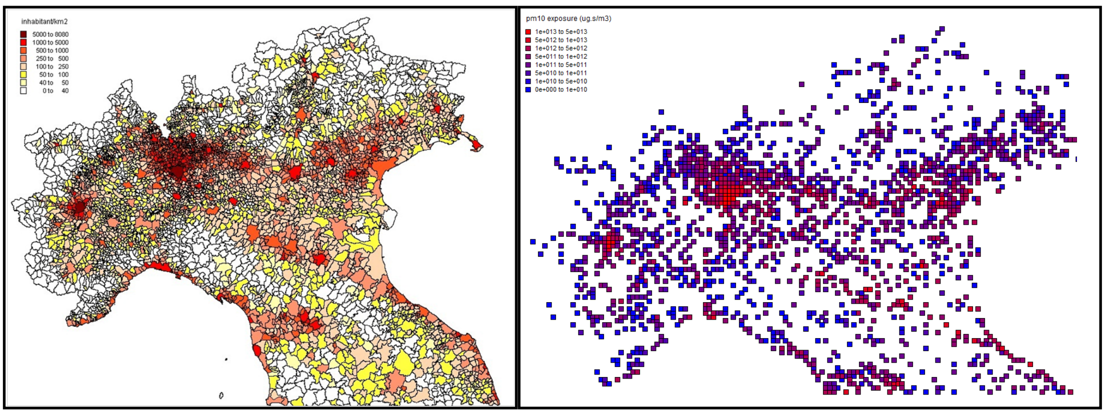

Figure 2. Left panel: population distribution for the Po Valley Region (provided by ENEA). Right panel: annual PM_{10} exposure *scaled to 1 km² grid cell* (µg.s/m^3) for the Po Valley region, 2005.

DISCUSSION

Analyzing the results obtained it is clear that exposure is very strongly spatially correlated with the population data. This is expected since emissions and concentrations are highest, in particular traffic-related emissions, where the population density is highest. This is most clearly visible in the Greater London case study. The Po Valley study shows a similar correlation between the population density distribution and the exposure results but we also see a strong influence of the topography of the terrain. The Alps in the northern part of the domain create a specific situation in terms of dispersion of the pollutants, trapping the pollution within the valleys closer to the mountains and increasing the exposure to pollutants.

The methodology described and implemented here provides the basic exposure assessment for the study areas, i.e. long term exposure at home residences. The poor temporal resolution (1 year average) may lead to severe underestimation, in particular, exposure related to traffic (short term exposure). Local, detailed activity data would be needed to assess properly the uncertainty related to the rough temporal resolution For assessing short term exposures it would be crucial to have better temporal resolution On the other hand, assessing long term exposures to ambient air 'properly' one should take into account the time activity and hence have a model temporal resolution to reflect that. Even so, the time activity data would always be aggregated (i.e. week day and weekend diurnal averages) and the model results would actually not be needed for every hour but should reflect the diurnal and weekly cycles. For estimating these cycles, information about microenvironments and how these impact on the ambient concentration is needed.

This modeling analysis has also a number of other inherent limitations and uncertainties. There are uncertainties concerning the emission and population inventories and regarding the dispersion modelling. Since the models and inventories here utilized were different, the detailed uncertainties related to these will also be different. In general, population inventories are not compiled very frequently, census is typically carried out every 10 years, and in cities like London the spatial distributions of population can be very dynamic, significant changes in the population densities can occur even in a 1 year timeframe There are always large uncertainties with emission inventories (typically +-50%) and the temporal and spatial resolution of these inventories might not be compatible with the spatial and temporal resolution of the dispersion model. Also the dispersion models utilized in this study have different requirements in terms of input data and the intrinsic physical processes that must be solved mathematically differently since their simulation domain is quite different: local/urban scale for Greater London and regional scale for the Po Valley region.

Denby *et al* (2011) accessed the sub-grid variability and the consequent impact on human exposure computations for the same spatial areas as the present study. Since these two studies were conducted for different years, the results presented above (see Results section) are only suitable to estimate the order of magnitude of the values for population averaged concentrations and being compared with the values obtained by Denby *et al* (2011).

The population averaged concentrations obtained from the exposure study for the Greater London is 24.5 µg/m^3 for PM_{10}. When comparing with the study by Denby *et al* (2011)., the values for the latter study are much smaller, but for this particular domain, only one grid cell is considered from the EMEP calculations, bearing in mind that the reference year for the computation is different, which is already enough to enough to explain the difference between the values. For the Po Valley region case, the values obtained by these two different modeling studies for PM_{10} are much closer to each other: according to the higher resolution exposure study the population averaged concentrations for PM_{10} are 27.1 ug/m^3 and 42.4 µg/m^3 for NO_2,while the values range between 16.5-19.3 ug/m^3 in the EMEP modeling based study. The results for Po Valley are much more comparable since the years studied are much closer, so at least the emissions will be more similar, and the number of grid cells used for the PoValley region study by Denby *et al* (2011) is much more representative.

CONCLUSION

Exposure results show a strong spatial correlation with the population data. This is expected since emissions (traffic especially) and concentrations are highest where the population density is highest. In the case of Po Valley region we also see a strong influence of the topography of the terrain. The Alps create a specific situation in terms of dispersion of the pollutants, trapping the pollution within the valleys closer to the mountains and increasing the exposure to pollutants.

The population averaged concentrations obtained from the Greater London exposure study is 24.5 µgPM_{10}/m^3 and 27.1 µgPM_{10}/m^3 for Po Valley region. The difference in population weighted concentration estimates (and exposures) are 1.5-2 times higher in the high resolution study. Additionally, these results were qualitatively compared with the population averaged concentrations obtained by Denby *et al* (2011), since the studies were conducted for different years. The values obtained for Po Valley region by these two different modelling studies for PM_{10} are much closer to each other, also more comparable since the years studied are nearer (similar emissions).

The methodology described and implemented here provides the basic exposure assessment for the study areas. While the spatial resolution of this assessment is satisfactory, we have at this stage only addressed annual average values. This probably leads to an underestimation of the exposure, especially the traffic related one (Karvosenoja *et al.*, 2010). In future work to improve the accuracy of this assessment, hourly time series of data could be considered.

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Union's Seventh Framework Programme FP/2007-2011 under grant agreement n°212520.

REFERENCES

CERC (2001) Validation of ADMS-Urban and ADMS-Roads against M4 and M25 Motorway Data, UK, www.cerc.co.uk/software/pubs/ADMS-Urban%20and%20Roads%20Validation%20M4%20M25.pdf.

Denby, B. R., M. Cassiani, J. Horálek, P. de Smet and F. de Leeuw, 2011: Sub-grid variability in regional scale air quality models and its impact on exposure assessment. *Atmospheric Environment*, **45**, Issue 25, 4220-4229.

Karvosenoja, N., L. Kangas, K. Kupiainen, J. Kukkonen, A. Karppinen, M. Sofiev, M. Tainio, V. Paunu, P. Ahtoniemi, J. T. Tuomisto and P. Porvari, 2010. Integrated modeling assessments of the population exposure in Finland to primary PM2.5 from traffic and domestic wood combustion on the resolutions of 1 and 10 km. Air Qual. Atmos. Health. DOI 10.1007/s11869-010-0100-9.

Zanini, G., T. Pignatelli, F. Monforti, G. Vialetto, L. Vitali, G. Brusasca, G. Calori, S. Finardi, P. Radice, and C. Silibello, 2005 : In. Zerger, A. and Argent, R.M. (eds.) MODSIM 2005 Int. Congress on Modelling and Simulation. Modelling and Simulation Society of Australia and New Zealand, 2005-2011.