FUTURE EMISSION SCENARIO ANALYSIS OVER ROME URBAN AREA USING COUPLED TRAFFIC ASSIGNMENT AND CHEMICAL TRANSPORT MODELS

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Abstract: The city of Rome is characterized by high ozone, NO_2 and PM_{10} levels claiming for the implementation of emission control strategies to improve the air quality and to decrease the risks of health effects on inhabitants. In this perspective an atmospheric modelling system based on the chemical transport model FARM has been applied for the year 2005 over a nested domain including the metropolitan area. To improve the description of local scale atmospheric circulation characteristics, observational meteorological data are analysed using the Isentropic Analysis package (ISAN). Since urban traffic emissions represent a relevant source of pollutants, hourly emissions coming from this sector have been estimated by means of a traffic assignment model, based on a source-destination approach, coupled with an emission model based on COPERT-3 methodology. The emissions from the other sectors have been derived from the national inventory and then disaggregated at the municipal level. The analysis of model results for the year 2005 against experimental data reveals a good agreement suggesting the use of the modelling system to study the impact on the air quality of different emission control strategies at both regional and urban scales. The 2010 has been considered as the future year base case scenario and the traffic limitation within the Rome urban core has been considered as an emission control action. The impact of this emission scenario has been then analysed by means of a semi-empiric approach: a significant decrease of PM_{10} and NO_2 yearly average concentrations is expected to occur at urban traffic stations while the minimum reduction is expected at urban background and rural stations.

Key words: *Air quality assessment and management, modelling, traffic emission, urban air pollution, emission control strategies.*

1. INTRODUCTION

Rome is the largest metropolis in Italy with a surface area of 1290 km^2 and about 3 million inhabitants. Its primary road network has a total length of 700 km plus a huge number of smaller roads and a few highways which take commuters downtown. According to the local environmental authority (ARPA Lazio), the air pollution is mainly characterized by high NO_2, O_3 and PM_{10} levels. The annual concentration of NO_2 is above the standard value for human health protection (40 $\mu g\ m^{-3}$) while the hourly law limit of 180 $\mu g\ m^{-3}$ for ozone is exceeded several times at some monitoring stations. As for PM_{10}, the mean annual value is above the law limit of 40 $\mu g\ m^{-3}$ at urban traffic stations, with the maximum number (35) of exceedances of daily human health protection limit, fixed at 50 $\mu g\ m^{-3}$, violated by several stations. The incoming 2010 air quality guidelines will introduce new limit values that will probably not be met, claiming for the implementation of emission control strategies to improve the air quality and to decrease the risks of health effects on inhabitants. Modelling techniques are the tools that are commonly used to assess the impact of emission strategies on air quality levels. In this perspective, a modelling system previously adopted to simulate winter and summer pollution episodes occurred over Rome urban area (Gariazzo *et al.* 2007) has been used to check, on an annual base, its capability to reproduce air quality levels in the studied area and therefore to simulate future emission scenarios. In the next sections a description of the modelling system and the main results obtained by its applications are discussed. The analysis of the effects of future emission scenarios on air quality are analysed in the following section.

2. 2005 AIR QUALITY ASSESSMENT

To consistently take into account the effect of local as well as remote sources and to describe processes (e.g. sub-synoptic flow features, photochemical smog) dominated by scales larger than the city's one, an approach considering two nested domains was adopted (Fig. 1): the regional domain includes a significant portion of Central Italy (66x58 cells at 4 km of grid spacing) while the target domain includes Rome urban area (61x61 cells at 1 km of grid spacing).

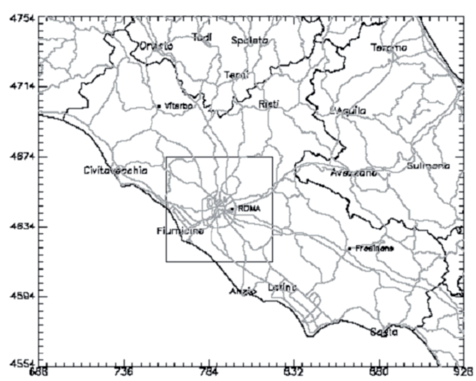


Figure 1. Area under study: Lazio region (Central Italy) and Rome conurbation domains.

The atmospheric modelling system (AMS) used to reconstruct air quality maps over the two domains include four subsystems respectively used to: reconstruct flows and related turbulence parameters; apportion data from the emission inventories to grid cells, perform air quality simulations over the selected domain and compute air quality indicators required by the EC directives. The AMS is based on FARM model (Flexible Air quality Regional Model, Silibello et al., 2008) that has been applied with the *SAPRC-90* (Carter, 1990) chemical mechanism and the *aero3* modal aerosol scheme implemented in CMAQ framework (Binkowski, 1999; Binkowski and Roselle, 2003). Climatologically boundary conditions for all modelled species on the regional domain have been derived from the corresponding three-dimensional fields obtained by national scale simulation produced in the frame of MINNI project (Integrated National Model in support to the International Negotiation on air pollution, Zanini *et al.* 2004). In such way the regional-scale simulation takes into account the influence of sources located outside the selected domain. Since the air quality in Rome is strongly affected by local circulation structures (e.g. katabatic and anabatic thermal winds and land-sea breezes), national scale meteorological fields have been improved by applying the RAMS Isentropic Analysis (ISAN) package (Walko and Tremback, 1995) to perform high resolution meteorological analyses over Lazio and Rome target domains for the whole 2005 year. ISAN implements an optimal interpolation method based on Barnes algorithm to iteratively correct background fields with the meteorological stations from ARPA (Regional Environmental Protection Agency) and SMAM/WMO (Air Force Meteorological Service/World Meteorological Organization) monitoring networks. The regional and urban scale meteorological fields together with land cover information (e.g. roughness length) and chemical species characteristics (gas reactivity), have been then used by interface module GAP/SURFPRO (Finardi et al., 2008; FUMAPEX, 2006) to produce dry deposition velocities and turbulent diffusivity fields needed by FARM. The emissions coming from major industrial facilities and the diffuse sources over the considered domains were derived from the national emission inventory for the year 2000 (APAT, 2004) and projected to the simulated year using national trends differentiated for each pollutant and activity. A detailed analysis of PM_{10} and NMVOC emissions coming from heating sector (Non-Industrial Combustion Plants) and the on-field burning of stubbles has revealed a significant underestimation, probably due to the evaluation of the firewood used and the stubble burnt. For this reason the values proposed in the RAINS-Italy model (Vialetto *et al.*, 2005; Zanini et al., 2005) have been used instead and also for other sources not included in the national inventory: construction and other residential combustion activities (e.g. fireworks, meat frying, food preparation and barbeques).

Figure 2. Rome municipality road network.

A more detailed approach has been adopted for traffic emissions using the results coming from a model, routinely used by ATAC (Rome mobility agency), that considers the entire regional territory and the transport network. Traffic assignment has been carried out using by TransCAD software (http://www.caliper.com/tcovu.htm) that combines Geographic Information System (GIS) and transportation modelling capabilities to store, display, manage, and analyse transportation data. The multimodal equilibrium traffic assignment procedure has been adopted to assign cars, trucks and buses to the road network, made up of 6000 links (Fig. 2), on the basis of surveys conducted by ATAC considering trips that have origin or destination within Rome municipality, or using Rome transport network but originating and ending outside the municipality. Origin/destination matrixes were then assigned to the network obtaining hourly traffic flows on road links for each day of the week. Traffic flows related to Rome urban network and highways located within the studied area have been then processed by TREFIC model (Nanni and Radice, 2004) that implements COPERT III (Ntziachristos and Samaras, 2000) approach and includes IIASA emission factors for the treatment of PM (IIASA, 2001). The AMS provided with the such input data has been then used to perform the 2005 air quality assessment over regional and urban domains. Since the major concern is related to PM_{10} and NO_2 ambient concentrations the comparison between 2005 observed and estimated Air Quality Objectives for protection of human health for such pollutants is given in the following Figure 3 evidencing a good agreement between observed and predicted indexes.

PM_{10}, annual mean (40 $\mu g\ m^{-3}$) | PM_{10}, 24-hour mean (50 $\mu g\ m^{-3}$, not to be exceeded more than 35 times a year) | NO_2, annual mean (40 $\mu g\ m^{-3}$)

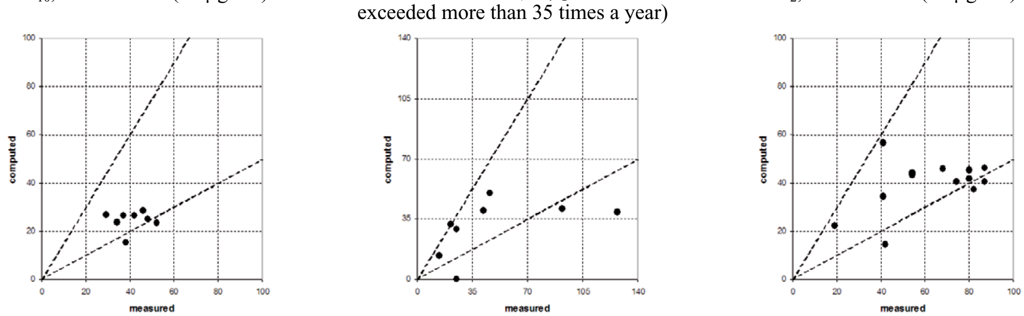


Figure 3. Comparison between observed (abscissa) and estimated (ordinate) Air Quality Objectives for the protection of human health at different monitoring stations. Between parenthesis EU air quality standards. Reference year: 2005.

The uncertainty is generally between ±50%, with underestimations of observed levels at hot spots corresponding to high traffic sites, confirming the accuracy of input data provided to the AMS and encouraging its application to evaluate the impact of different emission control strategies on air quality standards.

3. 2010 EMISSION SCENARIOS ANALYSIS

After the definition of present-state situation the medium term demand level was estimated including a complex set of actions on private and public transport involving the set-up of two new subway lines, new road and parking infrastructures, new reserved public transport route, new railway urban connections able to increase in total the PT seats/km from 5,8 to 8,2 millions and the geographical development of the city that influence the modal distribution and the spatial distribution and the total amount of mobility. On this basis, two different forecast models were applied to estimate future numbers of inhabitants and workers leading to the new mobility demand: trips will grow by 4% (584.000 against present 563.000). As for the other sources, the trends defined by RAINS-Italy Current Legislation (CLE) Scenario, which assumes the implementation of all presently decided emission-related legislation in EU-25 countries, have been considered to derive the regional emissions for the year 2010. Table 1 reports present-state and 2010 estimated emissions for Rome municipality confirming the relevance of road traffic sector emissions.

Table 1. Base case (top) and Future scenario (bottom) emissions for Rome municipality [ton/year].

	CO	NMVOC	NH_3	NO_X	SO_X	PM_{10}
Combustion in Energy and Transf. Industries	28	975	0	924	81	89
Non-Industrial Combustion Plants	15933	2646	0	4501	2230	2231
Combustion in Manifacturing Industry	125	36	1	2144	133	134
Production Processes	3	699	0	0	126	178
Extraction and distrib. of fossil fuels and geothermal Energy	0	1578	0	0	2	2
Solvent and other product use	0	12078	0	0	0	0
Road Transport	76950	8070	693	15459	350	810
Other Mobile Sources and Machinery	3736	621	0	2678	174	184
Waste Treatment and Disposal	1615	135	44	68	49	74
Agricolture	41	15	1108	1	3	14
Othes Sources and Sinks (+ PM-RAINS)	0	213	0	0	726	995
Total	**98432**	**27068**	**1846**	**25776**	**3873**	**4711**

	CO	NMVOC	NH_3	NO_X	SO_X	PM_{10}
Combustion in Energy and Transf. Industries	28	975	0	1317	95	105
Non-Industrial Combustion Plants	15496	2575	0	4635	1966	1967
Combustion in Manifacturing Industry	128	37	1	2349	146	148
Production Processes	3	714	0	0	138	196
Extraction and distrib. of fossil fuels and geothermal Energy	0	1604	0	0	2	2
Solvent and other product use	0	11847	0	0	0	0
Road Transport	55028	5863	647	10282	351	730
Other Mobile Sources and Machinery	3787	631	0	2610	170	180
Waste Treatment and Disposal	1620	135	27	68	49	74
Agricolture	41	15	1090	1	3	13
Othes Sources and Sinks (+ PM-RAINS)	0	213	0	0	364	505
Total	**76132**	**24610**	**1764**	**21262**	**3285**	**3919**

To have a more realistic representation of ambient concentrations in the future scenario, an approach based on "rollback" model has been adopted. Rollback is a very simple model in which ambient concentrations are assumed to be proportional to emissions. Following this approach, observed and future concentrations of a species A in a generic site may be written as follows: $C_A^{obs} = C_B + KE_A^{Present}$, $C_A^{Scenario} = C_B + KE_A^{Scenario}$ where C_B is the background concentration and K the proportionality factor between concentrations and emissions. C_B and K are assumed to not vary in the present and future scenarios. Combining these equations we obtain:

$$C_A^{Scenario} = C_B + (C_A^{obs} - C_B) \cdot \frac{E_A^{Scenario}}{E_A^{Present}} \tag{1}$$

According to Im *et al.* (2005), a good predictor for modelled concentrations in the future scenario is given by the following relationship:

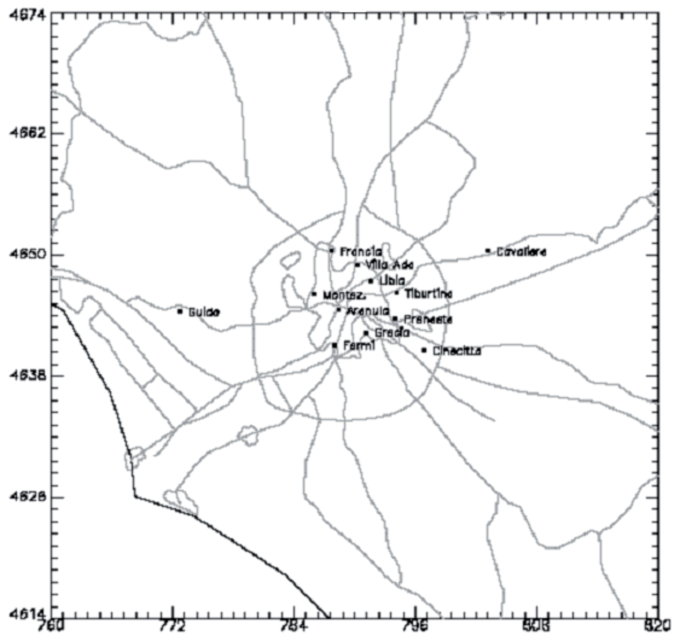
$$C_A^{Scenario,modelled} = C_A^{Present,modelled} \cdot \left(\frac{E_A^{Scenario}}{E_A^{Scenario}} \right)^{\gamma} \tag{2}$$

where the exponent γ has been then derived as the median of the distribution obtained by applying linear optimisation techniques at selected points corresponding to the monitoring stations ($C_A^{Scenario,modelled}$ was considered the objective function). Substituting [2] in relation [1] we obtain the following formula:

$$C_A^{Scenario} = C_B + (C_A^{obs} - C_B) \cdot \left(\frac{C_A^{Scenario,modelled}}{C_A^{Present,modelled}} \right)^{1/\gamma} \tag{3}$$

that has been used to estimate the concentration levels at monitoring sites for the future emission scenario. The main advantage of [3] is that observed and computed concentration are tied together leading to more realistic estimation of the concentration in the future scenario; moreover the use of the ratio between modelled concentrations implicitly include physical and chemical processes considered by the CTM.

The combined use of above formulas permits to compare 2005 (observed) and 2010 PM_{10} and NO_2 Air Quality Objectives for protection of human health at different sites (see Figure 4). Following values for C_B and γ have been used in (3): 5 $\mu g\ m^{-3}$ and 0.72 for NO_2 and 10 $\mu g\ m^{-3}$ and 0.85 for PM_{10}. The analysis of the following Figure 5 evidences that a significant decrease is expected to occur for such species particularly at urban traffic stations (see the results for Francia and Fermi stations) while the minimum reduction is expected at urban background Villa Ada station and natural background stations (Guido e Cavaliere).



Station	*Type*
Cavaliere Guido	*Natural Background*
Villa Ada	*Urban Background*
Cinecitta' Preneste	*Urban*
Arenula Fermi Francia Grecia Libia Montezemolo Tiburtina	*Urban Traffic*

Figure 4. Location and characteristics of monitoring sites considered in the study

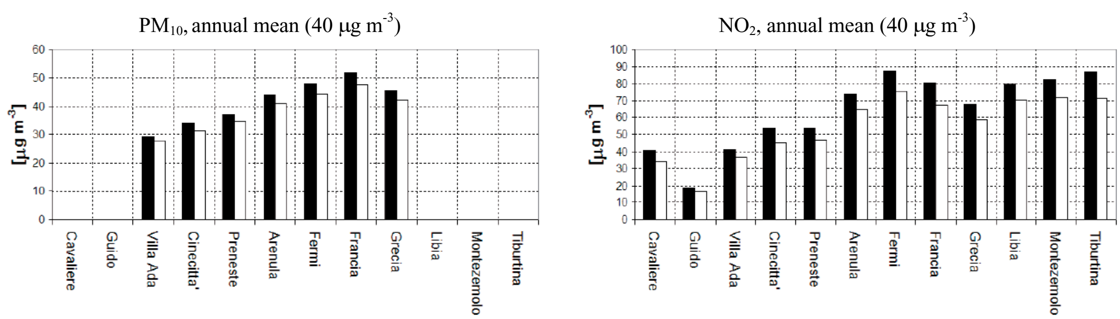


Figure 5. Comparison between 2005 (black) and 2010 (white) Air Quality Objectives for protection of human health. Between parenthesis EU air quality standards.

4. SUMMARY AND DISCUSSION

The results obtained in this study confirm the relevance of modelling tools to support the assessment and management of regional air quality. The complementary use of state-of-science photochemical models, adequately fed by meteorological drivers and detailed regional emission inventories, and measurements provided by the air quality networks allows to achieve a good description of the spatial distribution of atmospheric pollutants and to identify, according to EU Directives, unattainment areas for which action plans have to be developed. This approach has been successfully applied for the assessment and the management of air quality in the urban area of Rome. A special attention has been provided to the emissions estimation of the urban traffic, by using high detailed traffic data derived by a special traffic assignment model, which has been coupled with a chemical transport model. Results have shown the capability of the modelling system to reproduce the observed pollutants concentrations and the air quality objectives levels. The uncertainty is generally between ±50% with underestimations of observed levels at hot spots corresponding to high traffic sites probably not well resolved at the horizontal scale adopted by the model (1 km).

These performances have also encouraged its application in investigating the impact of future emission control strategies on air quality. Since the major concern in Rome conurbation is related to nitrogen dioxide and to PM_{10}, generally during the winter season and in areas affected by nearby traffic emissions, the models have then be applied to a future year mobility emission scenario. To tie more effectively observed and computed concentrations and to lead to a more realistic estimation of the concentration in the future emission scenario, a model based on rollback assumption has been applied. As far as the 2010 Air Quality Objectives for protection of human health are concerned, a significant decrease is expect to occur for PM_{10} and NO_2 at urban traffic stations, while minimum reduction is expected at urban background areas. The analysis of the impacts of such scenario evidences an improvement of the air quality over the conurbation not sufficient, nevertheless, to meet the prescribed standards particularly at urban-traffic sites. For such reasons further emission control strategies will be considered by the Regional Authorities, by means of the described modelling system, to improve more effectively the air quality over Rome urban area.

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REFERENCES

APAT Agency for Environmental Protection and Technical Services, 2004. La disaggregazione a livello provinciale dell'inventario nazionale delle emissioni – Rapporto Finale (in italian)

Binkowski, F. S., 1999: The aerosol portion of Models-3 CMAQ. In Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. Part II: Chapters 9-18. D.W. Byun, and J.K.S. Ching (Eds.). EPA-600/R-99/030, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC, 10-1-10-16.

Binkowski, F.S. and S.J. Roselle, 2003: Models-3 community multiscale air quality (CMAQ) model aerosol component 1. Model description. *Journal of Geophysical Research*, **108** (D6), 4183.

Carter, W.P.L, 1990: A detailed mechanism for the gas-phase atmospheric reactions of organic compounds.

Finardi, S., R. De Maria, A. D'Allura, C. Cascone, G. Calori and F. Lollobrigida, 2008: A Deterministic Air Quality Forecasting System For Torino Urban Area, Italy. *Environmental Modelling and Software*, **23**, 344-355

FUMAPEX, 2006: Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure: Final Project Scientific Report. In Baklanov, A. (Ed.). http://fumapex.dmi.dk.

Gariazzo C., C. Silibello, S. Finardi, P. Radice, A. Piersanti, G. Calori, A. Cucinato, C. Perrino, F. Nussio, M. Cagnoli, A. Pelliccioni, G.P. Gobbi and P. Di Filippo, 2007: A gas/aerosol air pollutants study over the urban area of Rome using a comprehensive chemical transport model. *Atmosp. Environ.* **41**, 7286-7303.

IIASA, 2001: RAINS-Europe http://www.iiasa.ac.at/~rains/home.html.

Im, H. K., M.L. Stein and V.R.Kotamarthi, 2005: A new approach to scenario analysis using simplified chemical transport models. *Journal of Geophysical Research*, **110**, D24205.

Nanni, A. and P. Radice, 2004: Sensitivity analysis of three EF methodologies for PM10 in use with climatological dispersion modelling in urban Italian study cases. *Proc. of 9th Int. Conf. on Harmonisation within Atm. Dispersion Modelling for Regulatory Purposes, 1–4 June 2004, Garmisch-Partenkirchen,* **1**, 309-314.

Ntziachristos, L. and Z. Samaras, 2000: Computer programme to calculate emissions from road transport. Methodology and emission factors (Version 2.1). *EEA Technical report* No **49**.

Silibello, C., G. Calori, G. Brusasca, A. Giudici, E. Angelino, G. Fossati, E. Peroni and E. Buganza, 2008: Modelling of PM10 Concentrations Over Milano Urban Area Using Two Aerosol Modules. *Environmental Modelling and Software*, **23**, 333-343.

Vialetto, G., M. Contaldi, R. De Lauretis, M. Lelli, V. Mazzotta and T. Pignatelli, 2005: Emission Scenarios of Air Pollutants in Italy using Integrated Assessment Models. *Pollution Atmosphérique*, **185**, 71.

Walko, R.L. and C.J. Tremback, 1995: RAMS The Regional Atmospheric Modeling System (Version 3b) User's Guide. ASTeR, Inc. (http://www.atmet.com/html/docs/documentation.shtml).

Zanini, G., F. Monforti, P. Ornelli, T. Pignatelli, G. Vialetto, G. Brusasca, G. Calori, S. Finardi, P. Radice and C. Silibello, 2004: The MINNI project. In: Suppan, P. (Ed.), *Proceedings of 9th Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 1-4/6/2004, Garmisch-Partenkirchen.*

Zanini, G., T. Pignatelli, F. Conforti, G. Vialetto, L. Vitali, G. Brusisca, G. Calori, S. Finardi, P. Radice and C. Silibello, 2005: The MINNI Project: An Integrated Assessment Modeling System For Policy Making. *Proceedings of the 15th MODSIM congress: "Advances and Applications for Management and Decision Making", Melbourne, Australia, 12-15 December 2005.*