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FORECAST AND NEAR REAL TIME AIR QUALITY MODELING SYSTEMS FOR ROME METROPOLITAN AREA: DESCRIPTION AND PRELIMINARY PERFORMANCE EVALUATION

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Abstract: This study describes and evaluates two modelling systems developed to provide air quality forecasts and nowcasts over Rome metropolitan area and its surrounding. The systems have been implemented by the regional environmental protection agency (ARPA Lazio) to satisfy the air quality *Directive 2008/50/CE* requirements. The meteorological model RAMS has been used to reconstruct 3D meteorological fields that drive the Eulerian chemical transport model FARM. Industrial and domestic emission fluxes are based on a local high resolution emission inventory while emissions from road traffic have been estimated by means of traffic modelling. The forecasting system is part of Chemical Weather Forecast Network, promoted by COST ES0602 Action, and provides 72 hours predictions published on ARPA Lazio web site, allowing to identify possible exceedancees of EU air quality standards. The nowcasting system includes a data assimilation module based on the Successive Correction Method (SCM) that considers O_3, NO_2, Benzene, CO and SO_2 measurements. 34 monitoring stations (industrial, urban, suburban and rural) from the regional monitoring network have been used. Air quality analyses are available every 3 hours. A statistical analysis has been applied to evaluate the performance of the two systems and verify their ability to predict/reconstruct air pollution episodes. The evaluation has been based on standard air quality model evaluation indexes and graphics. Both systems show a good agreement with observed levels for the Rome metropolitan areas. The Near Real Time (NRT) system, that uses data-assimilation techniques, show a better performance when compared with experimental data suggesting indications on the more convenient way to get air quality assessment on the fly over Rome metropolitan area. Main weaknesses emerged for the rural area surrounding Rome conurbation claiming for an improvement of the emission inventory.

Key words: *Air Quality, Forecasting system, Near Real Time system, data assimilation, SCM, Rome.*

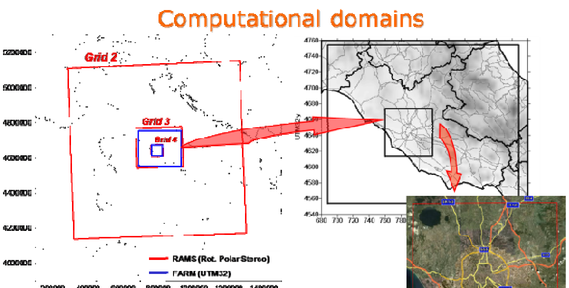
INTRODUCTION

As provided by the air quality *Directive 2008/50/CE*, modelling is considered a powerful tool to assess and manage air quality (AQ). In Italy, to date, only few Regional Environmental Protection Agencies (ARPAs) have implemented models to integrate information coming from air quality monitoring networks and support the definition of measures to reduce health impact of air pollution. The aim of this work is to analyse the performances of two modelling systems implemented by ARPA Lazio to provide air quality forecast and nowcast over Rome metropolitan area and its surrounding. The systems are based on the Eulerian Chemical Transport Model (CTM) FARM (Flexible Air quality Regional Model, Silibello *et al.*,2008) that has been recently improved by introducing data assimilation techniques (observational nudging and objective analysis: Optimal Interpolation – OI - and Successive Correction Method – SCM) in order to estimate an atmospheric status as close as possible to the reality, dynamically consistent and integrating all the available information: observations, model results, emission patterns and physical-chemical constraints.

The analysis of the results produced by the two systems has been performed by means of statistical indexes such as bias, root mean square error and absolute error to quantify differences between observations and model predictions regardless of observed or predicted concentrations levels, while other indexes defined as categorical indexes are used to measure forecasting skill in terms of correctly/incorrectly predicting concentration levels above/below a certain threshold.

DESCRIPTION OF THE MODELLING SYSTEM

The two systems are based on the same framework of four modelling modules: the emissions pre-processing system EMMA which is fed with local high resolution emission inventory (Rome road network emissions are derived from a proper traffic model; Gariazzo *et al.*, 2007); the prognostic non-hydrostatic meteorological model RAMS (Cotton *et al.*, 2003) to reconstruct 3D meteorological fields; the interface module GAP/SurfPRO for the estimation of dispersion parameters (Finardi *et al.*, 2008; FUMAPEX, 2006) and the CTM FARM to derive air pollutants concentration fields. The systems are applied on two target domains (Figure 1): a regional domain including the whole Lazio Region (g3) and a metropolitan domain focusing on Rome urban area (g4) that have respectively a horizontal resolution of 4 and 1 km. The NRT system differs from the forecasting system by the analyses phase performed by FARM with the Successive Correction assimilation Method that take into account O_3, NO_2, Benzene, CO and SO_2 measurements from the regional network including 34 monitoring stations (industrial, urban, suburban and rural). The NRT system produces air quality analyses every 3 hours, while the forecast system produces 72 hours forward on a daily basis. Results are freely accessible trough the ARPA Lazio web site (www.arpalazio.net) as surface concentration maps.



RAMS	Grid 1	Grid 2	Grid 3	Grid 4
Δxy (km)	32	16	4	1
Nx	54	58	66	70
Ny	54	58	58	70
Nz	32	32	32	32

FARM	Grid 3	Grid 4
Δxy (km)	4	1
Nx	61	60
Ny	51	60
Nz	12	12

Figure 1: Modelling system nested computational domains

ANALYSIS

In the following table (Table 1) are reported the standard and widely used measures of bias (Eder, 2005) and the forecast evaluation metrics used to evaluate the performances of the two modelling systems.

Table 1: Measures of bias and forecast evaluation metrics

Measures of bias	Forecast evaluation metrics		
$MB = \frac{1}{N}\sum_{i=1}^{N}(C_{mi} - C_{oi})$	Accuracy (%)	Percent of forecast that were correct	100 (A+D)/(A+BC+D)
$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(C_{mi} - C_{oi})^2}$	False Alarm Rate (FAR) (%)	Percent of forecasted exceedances that did not occur	100 B/(B+D)
$NME = \frac{\sum_{i=1}^{N}\lvert(C_{mi} - C_{oi})\rvert}{\sum_{i=1}^{N} C_{oi}} 100\%$	Probability of Detection (POD) (%)	Percent of observed exceedances that were forecasted correctly	100 D/(C+D)
$NME = \frac{\sum_{i=1}^{N}(C_{mi} - C_{oi})}{\sum_{i=1}^{N} C_{oi}} 100\%$	Critical Success Index (CSI) (%)	Measures how well high ozone events are predicted (not influenced by number of correct non-exceedance forecasts)	100 D/(B+C+D)
	where: A: Model correctly predicted no exceedance, B: Model predicted an exceedance that did not occur; C: Model failed to predict an exceedance that occurred, D: Model correctly predicted an exceedance		

The AQ System verification lasts the period from August to December 2009 and is mainly devoted to verify the modelling system capability to reproduce the observed concentration of major pollutants, to follow the observed concentrations time variations and to forecast relevant air pollution episodes. The comparison with observations has been extended to the regional and metropolitan domains (Figure 1) to identify resolution effects and possible influence of emissions treatment over the nested domains.

RESULTS

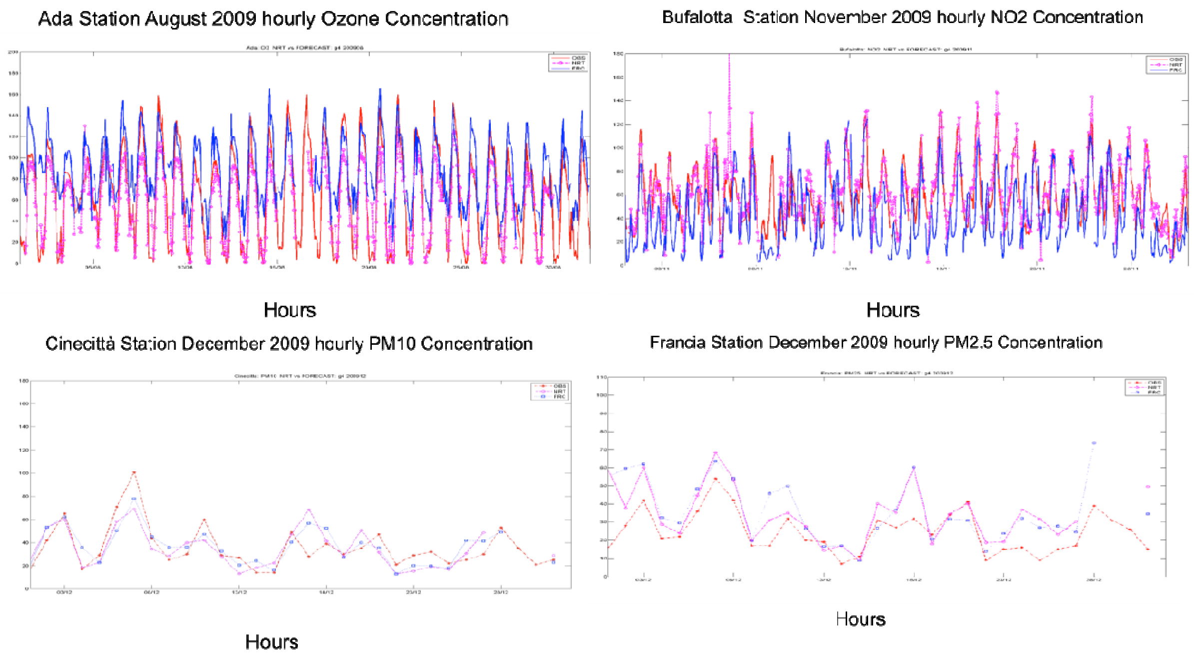


Figure 2. Temporal Series comparisons for NO_2, O_3, PM10 and PM2.5: Red indicates measurements, blue forecast system results and magenta NRT system results in the inner high resolution (1 km) domain.

The above figures show time series plots along different periods for a selection of stations. The red lines indicate measurements, the blue represent the model in forecast configuration and the magenta the model result in NRT configuration. At high resolution (Figure 2), both forecast and nowcast reproduce the pollutants trends well during the periods considered. For the summer period at the station of Ada, which is located inside a city park, the forecast catch the observed peaks better. This is due to the smoothing effect applying the assimilation algorithm to heterogeneous stations. At the contrary the nocturnal concentration are well reconstructed by the SCM. Even though the NO_2 maximums are well described by the two models, the NRT system shows a better capacity to describe local emission trends that can affect an urban residential station such as Bufalotta. It should be noted the good quality of results obtained for PM10 and PM2.5 daily average values. For the PM components small differences are obtained between the forecasting and the NRT systems because PM measurements are not employed in the assimilation process. This choice is due to the lack of hourly PM measurements and to the difficulty to assimilate daily average values. The statistics in Table 2 referred to stations located inside the Rome urban area confirm the good agreement of PM10 results for the Forecasting System. Negative and positive values of MB denote the difference between road side stations and urban background stations.

Table 2. Discrete Statistic for November –December 2009, PM10.

Station	Forecasting System 1 km PM10			
	MB	NMB	RMSE	NME
Preneste	-1.31	-4.52	8.94	23.96
Bufalotta	3.16	14.08	9.60	31.81
Cinecittà	-5.42	-17.84	10.23	26.01
Ada	2.66	11.28	8.21	27.64

Table 3 provides an example of categorical statistics calculated to evaluate the performance of the Forecast System during a critical winter period (December 2009). The system is characterized by an elevated Accuracy in every considered month, as reported e.g. in Table 3 for December. This parameter is influenced by the high number o f correctly forecast non exceedances and for this reason it is important to pay attention to the interpretation of this index in the evaluation of a forecasting system performances. The POD values are very high but in many cases the FAR index too, this is the reason why the CSI is low. It can also be noticed the variations of some parameters like FAR and CSI among the different considered stations. This behaviour can be attributed partially to the moderately polluted situations when concentration limits are exceeded only in some of the monitoring stations. These conditions are quite hard to forecast because the threshold values can be exceeded locally for a few $\mu g/m^3$ of concentration. Moreover, when exceedances are forecasted but in wrong position, while the forecast can still be considered positively its contribution to FAR and CSI will decrease performance indicators values.

Table 3. Categorical Statistic for December 2009, PM10, Forecast System, Resolution 1 Km

Station	Accuracy (%)	FAR (%)	POD	CSI
Preneste	77.78	60.00	100	40
Bufalotta	75.77	87.50	100	12.50
Cinecittà	82.76	50.00	60	37.50
ADA	82.14	83.33	100	16.67

The performances of the forecast system for Rome are well comparable with observed and NRT results. The coarse resolution domain (4 km) doesn't show a similar behaviour, especially outside Rome conurbation. Figure 3 highlights a significant model underestimation for NO_2. To understand the quite different results obtained for Rome and the surrounding region, it has to be reminded that Rome is the only large city in the area and all the remaining towns, where monitoring stations are located, have sub-grid size at the resolution of $4x4\ km^2$ and are surrounded by countryside. Moreover, monitoring stations are normally sited within town centres and nearby roads, making the reproduction of their measurements even more difficult. It has also to be mentioned that the emission inventory of Rome city is much more accurate than for the rest of the region, where large uncertainties are present. The NRT system maintains a very good concordance with experimental data for NO_2, whose measurements are directly assimilated, but not for PM10, which is not assimilated, highlighting the data assimilation process capability to locally recover poor performances due to insufficient resolution and deficiencies of emissions characterisation.

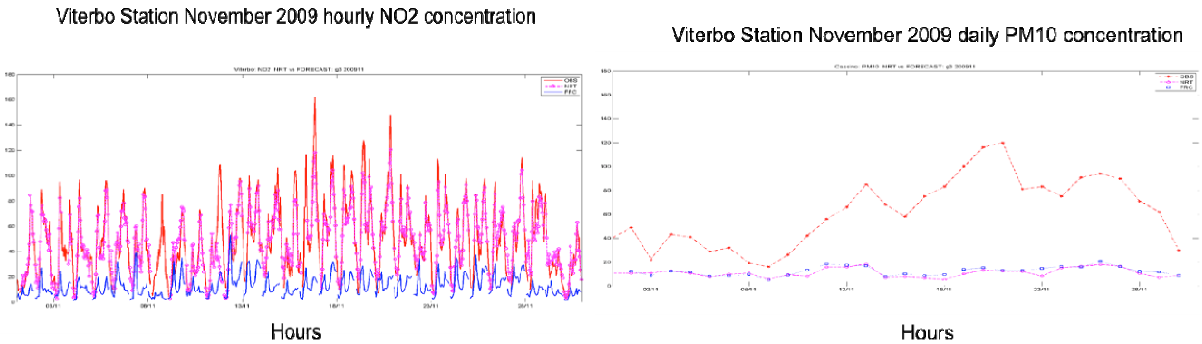


Figure 3. Temporal Series comparisons for NO2 and PM10: Red indicates measurements, blue forecast system results and magenta NRT system results in the outer low resolution (4 km) domain.

Table 2 shows results obtained for different stations located outside Rome at rural background, urban background and traffic locations. The value of RMSE for NO_2 confirms what is described above.

Table 4. Discrete Statistic for November –December 2009, NO_2.

Station	Forecasting System 4km NO_2				NRT System 4km NO_2			
	MB	NMB	RMSE	NME	MB	NMB	RMSE	NME
Cassino	-33.48	-65.41	39.49	66.90	-7.21	-13.85	19.19	18.87
Latina Scalo	-40.81	-80.96	49.07	81.29	4.93	9.58	11.46	17.30
Latina Tasso	-40.81	-82.23	49.46	82.23	12.06	23.38	18.96	28.87
Rieti	-28.57	-80.02	36.66	80.64	3.69	9.93	11.77	23.18
Leonessa	-16.20	-86.05	21.82	86.10	0.67	3.41	13.11	27.73

The monthly mean concentrations maps of NO2 (Lazio region) and PM10 (Rome urban area) produced by the NRT system for November 2009 are shown in Figure 4 in order to investigate the space distribution of concentrations and to understand the influence of each station employed in the assimilation process on the spatial distribution of pollutant concentration.

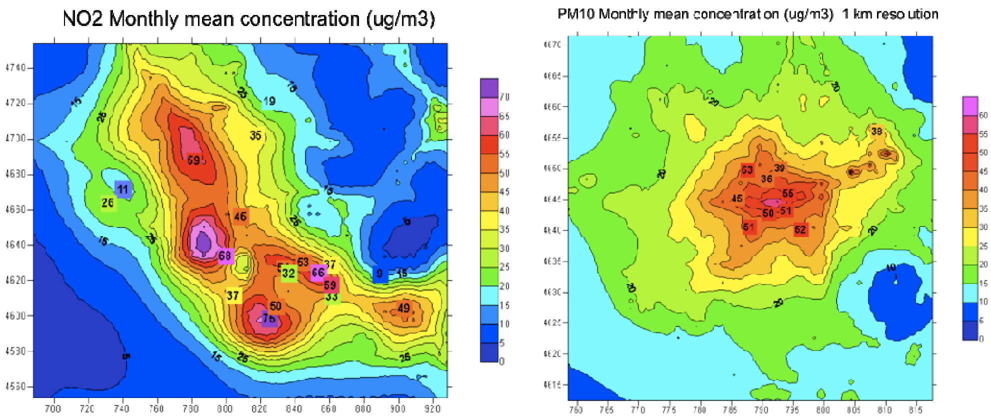


Figure 4: Comparison of daily average concentrations fields produced by the NRT modelling system (colored fields) and Lazio Region air quality network observations (colored square values) for NO2 (left) and PM10 (right) on November 2009. All concentrations are expressed in µg/m^3

Figure 4 shows that, for NO2, the NRT system qualitatively describes the areas where the observations individuate the higher concentrations and provides concentrations values very close to the observed ones. This feature is shown by PM10 map even if observed data has been not assimilated.

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