Operational multiscale modelling system for air quality forecast

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1 Introduction

The EU legislation fosters the development and use of air quality modelling systems for both air quality assessment (AQA) and air quality forecast (AQF). The Air Quality Framework and Daughter Directives (1996/62/EC; 1999/30/EC, 2000/69/EC and 2002/3/EC) encouraged European air quality management and assessment institutions to implement air quality modelling as one of the main sources of information to support periodic air quality assessment. Moreover the new Air Quality Directive 2008/50/EC places more emphasis on, and encourages, the use of models in in a wide range of applications. The new directive requires the distribution of air quality information for current day, together with trend and forecast for the next days and for the implementation of short term action plans, when concentrations are expected to exceed alert and information thresholds. Several scientific projects and initiatives have been supported by EU to enhance international cooperation on integrated meteorological and air quality modelling (COST 728) and on air quality forecast (COST ES0602, 5FP project FUMAPEX and 6FP project GEMS), and to promote the use of modelling for regulatory purposes (FAIRMODE). Different air quality modelling and forecasting system are presently in operational and pre-operational phase over Europe. Over the last few years ARPA Piemonte, taking advantage of the knowledge acquired during the 5FP project FUMAPEX, has developed a multi-scale air quality modelling system (Bande et al., 2007, Finardi et al., 2008) based on Eulerian chemical transport model. The operational version of this modelling system uses meteorological fields provided by COSMO-I7 to produce daily air quality forecasts. The following sections briefly describe the forecasting system architecture and present an overview of the modelling system performances; conclusions and future works are presented in the last section.

2 Air quality forecasting system description

The forecasting system has been built by using state-of-the-art techniques for atmospheric transport and dispersion modelling. The computational system architecture, sketched in Figure 1, is modular, so that the model inter-dependence is limited, in order to facilitate system improvements without modifying the general structure. The core of the system is represented by the air quality model FARM (Flexible Air Quality Model), three-dimensional Eulerian model that accounts for transport, chemical conversion and deposition of atmospheric pollutants (Gariazzo et al, 2007). The forecasting system needs a series of detailed input datasets: emission inventories, geographic and physiographic data (to describe topography, surface land cover and urban details), large scale air quality and meteorological forecasts. Some specific modules are needed to process these data in order to produce emissions, meteorological fields and boundary conditions necessary as input to the air quality model. Emission data (point, line and area sources) coming from different resolution inventories available over all computational domains are processed by a specific emission module in order to produce gridded hourly emission rates for all the chemical species considered by the air quality

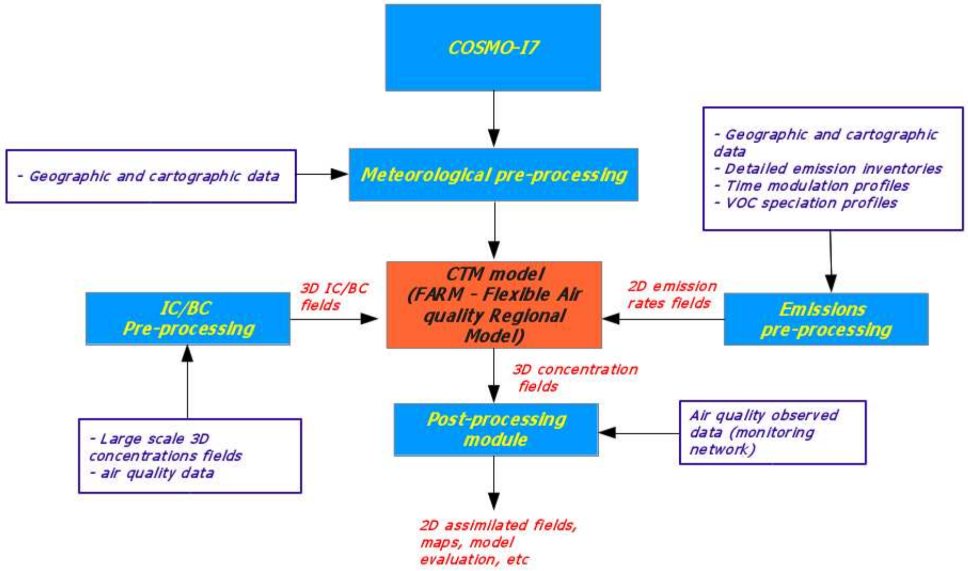

Figure 1: Forecasting system architecture.

model. This pre-processing system allows non-methanic hydrocarbon speciation and flexible space and time disaggregation, according to cartographic thematic layers and specific time modulation profiles (yearly, weekly and daily). The meteorological fields are provided by 00 UTC runs of COSMO-I7. The COSMO model levels fields are directly interpolated and adjusted (forced to be non-divergent) over all the computational domains by an interface module GAP/SURFPRO (Calori et al., 2006). GAP is a grid interpolation tool interfacing the chemical transport model FARM with any numerical weather prediction model. GAP interpolates a sequence of 2D and 3D atmospheric fields from a source grid identified by mesh points, geographic coordinates and altitudes, to a target grid defined using UTM projections and terrain-following vertical coordinates. Finally, starting from topography and land-use data managed by the modelling system and gridded fields of meteorological variables provided by COSMO-I7, SURFPRO (SURface-atmosphere interFace PROcessor) computes three-dimensional fields of horizontal and vertical diffusivity and two-dimensional fields of deposition velocities for a given set of chemical species. The initial and boundary conditions for the background domain are obtained by continental scale air quality forecasts provided by PrevAir European Scale Air Quality Service (http://www.prevair.org). The AQF modelling system performs simulations over three nested domains (Figure 2):

- a background domain, covering Po valley basin and the Alps, with an horizontal resolution of 8 km;
- a regional target domain, covering the whole Piemonte Region with an horizontal resolution of 4 km;
- three inner domains, with 1 km horizontal resolution, centred over Torino metropolitan area, Novara and Alessandria cities.

This multi-scale approach allows to take into account the effect of sources located outside the target areas, and to better describe phenomena characterized by large spatial scales, such as photochemical smog and particulate matter accumulation processes. The forecasting system runs on a daily basis in order to produce air quality forecasts for current day and the two days

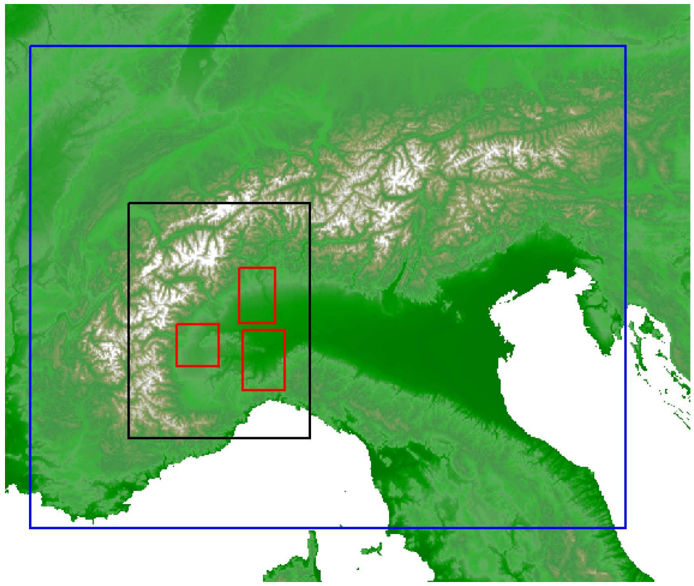

Figure 2: Forecasting system computational domains.

after, with one hour time resolution. The operational chain is organized in two main steps: during the first step the input data are acquired and processed, in the second step the air quality simulations are performed in two-way nesting mode. Finally, a post-processing phase followed by a product dissemination is carried out in order to produce the concentrations maps, to calculate all the air quality indicators required by the EU legislation and the Torino metropolitan area Air Quality Index (Giorcelli et al., 2008).

3 Overview of air quality forecasting system results

In this section we present an overview of the main results over the regional domain referred to almost one year period, from February 2012 to December 2012. The reliability of prediction for NO_2, PM_{10} and O_3 has been verified through comparison between the observed data coming from the regional air quality monitoring network and the simulated ones at corresponding station coordinates. Long term model performances have been evaluated using three statistical indexes selected among the more frequently used in air quality model evaluation studies: fractional bias (FB), root mean square error (RMSE) and Pearson correlation coefficient (ρ). The definition of the first two indexes is described below, where N is the number of observed-predicted data couples for each monitoring site, O_i and P_i represent respectively the ith observed and predicted values,and $\bar{O}$ and $\bar{P}$ the corresponding mean values.

$$FB = 2\frac{\bar{O}-\bar{P}}{\bar{O}+\bar{P}} \; ; \; RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - P_i)^2}$$

The results of model evaluation are reported in Table 1, while in Figure 3 are shown the box plots of observed and predicted concentrations in some monitoring stations for NO_2 (monthly distribution hourly mean) and O_3 (monthly distribution of daily maximum 8-hour running average). The comparison over a long period, including summer and winter months, underlines the modelling system capability to reproduce accurately seasonal and daily trends for all considered pollutants, with satisfactory correlation in almost stations and limited values of FB and $RMSE$; nonetheless all the considered stations show an underestimation ten-

Table 1: Statistical indexes for the validation sites

	PM_{10}			NO_2			O_3		
Station	FB	$RMSE$	ρ	FB	$RMSE$	ρ	FB	$RMSE$	ρ
Alba	0,646	25,757	0,528	0,456	18,903	0,596	0,017	23,687	0,852
Alessandria-Volta	0,507	29,968	0,539	0,41	27,266	0,463	-0,069	23,59	0,878
Asti	n.a.	n.a	n.a	0,23	18,231	0,656	0,027	22,758	0,872
Biella	0,312	14,548	0,517	0,11	15,342	0,62	0,09	20,822	0,879
Borgosesia	0,74	19,53	0,497	0,507	15,598	0,526	0,089	24,913	0,844
Cuneo	0,407	19,552	0,323	0,182	20,591	0,327	0,087	20,816	0,847
Cossato	0,599	19,276	0,594	0,424	16,183	0,709	-0,09	23,358	0,823
Dernice	0,385	12,188	0,425	0,4	8,279	0,573	0,014	24,713	0,783
Druento	0,465	20,243	0,426	-0,071	17,899	0,386	0,209	29,943	0,809
Novara-Verdi	0,351	19,863	0,519	0,103	18,729	0,619	0,029	22,923	0,875
Orbassano	n.a.	n.a	n.a	-0,045	21,689	0,535	0,266	31,041	0,808
Torino-Lingotto	0,081	25,222	0,582	-0,394	37,469	0,361	0,309	30,19	0,836
Vercelli-Coni	0,527	24,767	0,478	0,048	16,44	0,555	0,191	26,923	0,873
Verbania	0,587	16,826	0,388	0,427	16,684	0,526	-0,036	21,203	0,862
Vinchio	0,401	19,328	0,583	0,043	9,986	0,685	0,136	30,086	0,802
Vinovo	n.a.	n.a	n.a	-0,02	25,264	0,374	0,143	27,672	0,787
Torino-Consolata	0,245	27,181	0,608	0,006	27,029	0,467	n.a.	n.a.	n.a.

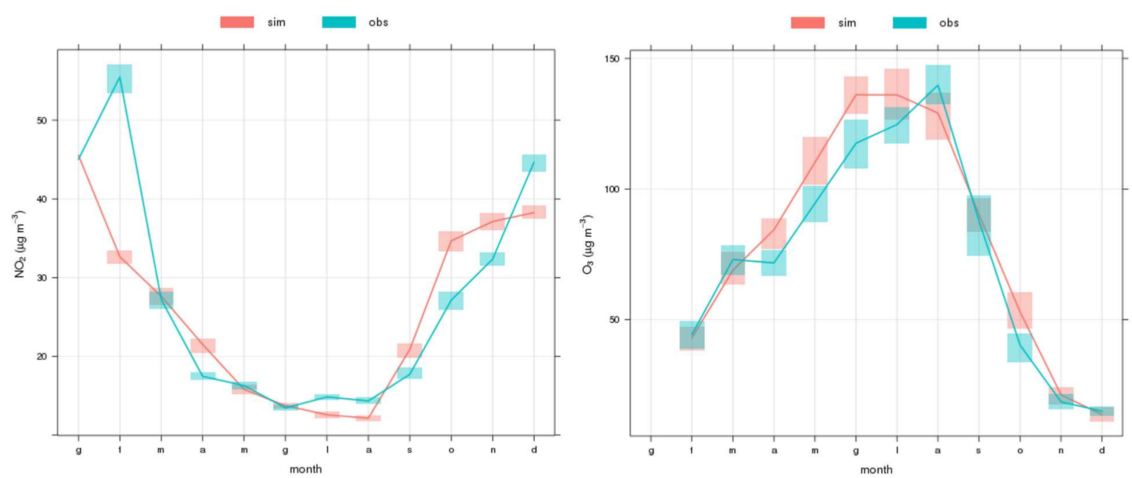

Figure 3: Box plots of observed (cyan) and predicted (pink) distributions: NO_2 hourly mean monthly distribution, Vercelli-Coni urban background station (left) and O_3 daily maximum 8-hour running average monthly distribution, Alessandria-Volta urban background station (right).

dency during wintertime. The statistical evaluation of results can be considered satisfactory for long term applications finalised to air quality assessment. The main request for those simulation is therefore to reproduce concentration distribution, providing a reliable evaluation of average and peak values through the estimation of indicators prescribed by EU directives. The requests become more stringent for air quality forecast, when concentration variations should be described with the correct space and time correlation. For a better insight of the possible influence on air quality simulations of meteorological fields, the time series of computed and observed concentrations have been analysed, with particular attention to air pollution episodes characterised by relevant time variation of measured concentrations. The comparison of time series (Figure 4) in two urban monitoring sites located in Torino and

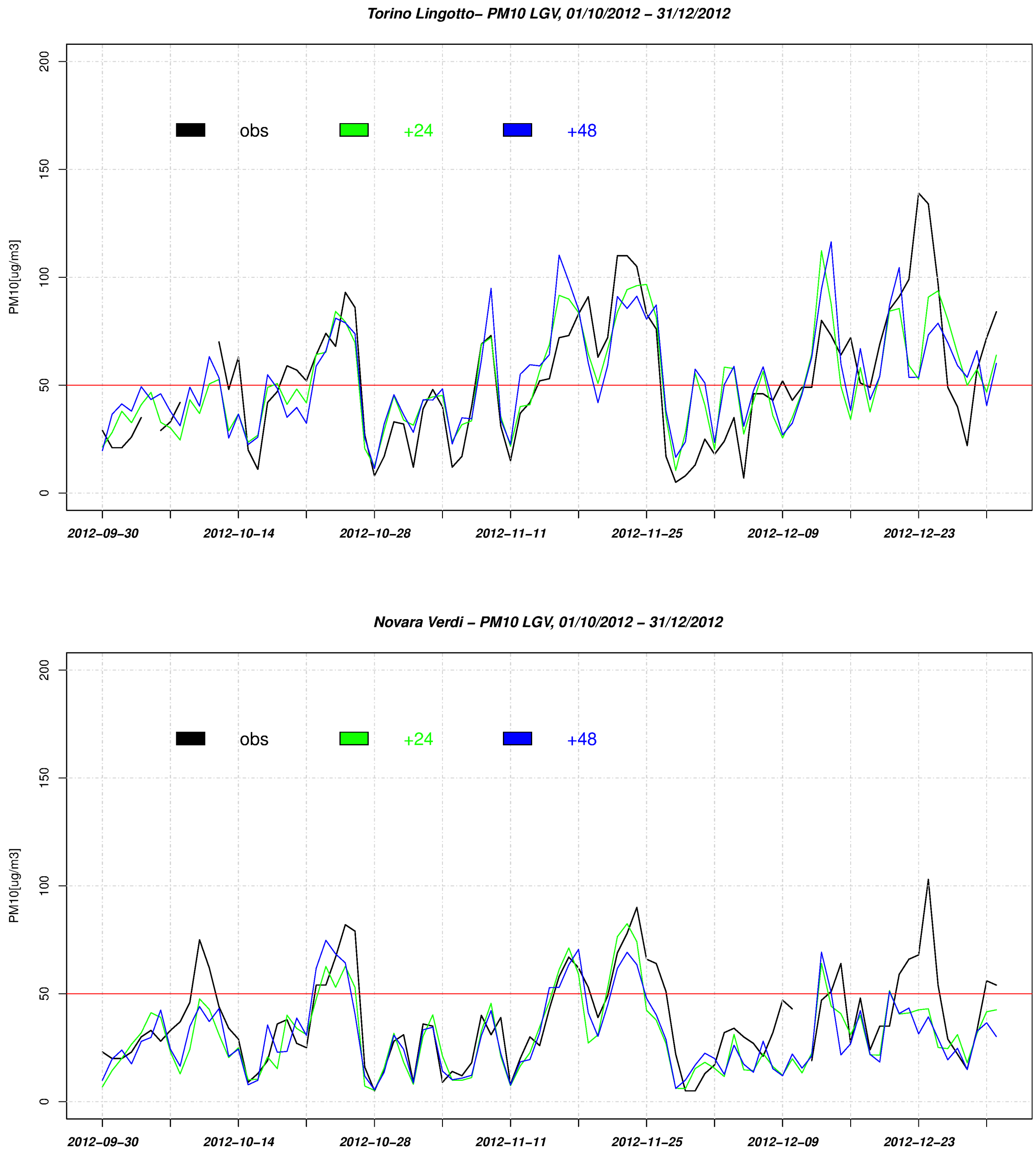

Figure 4: Time series of observed (black line) and predicted (green line +24 forecast, blue line +48 forecast) PM_{10} daily mean concentrations for the last three months of 2012: Torino-Lingotto (top) and Novara-Verdi (bottom) urban background stations.

Novara cities, shows that COSMO-I7 fields can provide a satisfactory capability to simulate meteorological forcing that can cause peak pollution episodes, even if weather forecast errors cause the occurrence of *false alarm* conditions with concentration overestimation.

4 Summary and Outlook

The analysis of results obtained by multiscale air quality forecasting system has confirmed its capability to forecast air pollutant episodes, concentration trends and mean levels. Some difficulties were found in the simulation of NO_2 and PM_{10} winter concentrations; this is probably due to a lack in domestic heating and vehicular traffic emissions estimation, but also to an insufficient description at locale scale of accumulation phenomena. In the near future, we are going to use COSMO-I2 as meteorological driver over target high resolution domains in order to provide a better reproduction of surface meteorological variables at locale scale. A second aim is to develop a near real time modelling system based on COSMO-I2 analysis (Galli et al., 2011) to provide daily analysis of previous day air quality levels.

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