Available online at www.sciencedirect.com
ScienceDirect
Environmental Modelling & Software 23 (2008) 333−343
Environmental Modelling & Software
www.elsevier.com/locate/envsoft

Modelling of PM_{10} concentrations over Milano urban area using two aerosol modules

C. Silibello [a,*], G. Calori [a], G. Brusasca [a], A. Giudici [b], E. Angelino [b], G. Fossati [b], E. Peroni [b], E. Buganza [c]

[a] *Arianet s.r.l., via Gilino 9, 20128 Milano, Italy*
[b] *ARPA Lombardia, viale Restelli 3/1, 20124 Milano, Italy*
[c] *Regione Lombardia, Direzione Generale Qualità dell'Ambiente, via Stresa 24, 20125 Milano, Italy*

Received 25 January 2007; received in revised form 2 April 2007; accepted 3 April 2007
Available online 23 May 2007

Abstract

Fine particulate air pollution represents one of the most relevant environmental concerns in Lombardia region (Northern Italy). PM_{10} concentrations overcome air quality limit values especially during wintertime, when frequently occurring thermal inversions and calm conditions tend to inhibit pollutants dispersion. To have a better understanding of the spatial distribution of PM_{10}, a modelling system has been applied to a winter PM_{10} episode considering a computational domain centered on Milano metropolitan area. The modelling system software suite is based on an Eulerian photochemical model (FARM − Flexible Air quality Regional Model) and includes an emission pre-processor to apportion data from the regional emission inventory, a diagnostic meteorological model coupled with a micrometeorological module and data visualization and post-processing tools. FARM model has been applied with two aerosol modules: the *aero3* modal aerosol module implemented in CMAQ framework and a bulk aerosol module (*aero0*), based on a simplified thermodynamic scheme. Both tested modules show a good agreement with observed concentrations. A performance analysis of modelling results by means of typical statistical measures has evidenced an acceptable model performance for both models and a better reproduction of PM_{10} levels using the more complete aerosol module (*aero3*). Furthermore, the application of the latter aerosol module provides a PM_{10} chemical composition that results in good agreement with data collected within Milano urban area.

Keywords: Urban air pollution; Particulate; Aerosol composition; Air quality modelling

Software availability

Name of software: FARM
Developers: Arianet s.r.l. (www.aria-net.it)
Availability and cost: Publicly available, contact address: info@aria-net.it.

1. Introduction

Lombardia is a densely inhabited and industrialised region located in Po Valley (Northern Italy) which is often affected by high ozone levels during summer months and by elevated PM_{10} and NO_2 concentrations during the cold season. The major urbanized and industrial conglomeration within the Region is the ''Milano−Como−Sempione critical area'', for which local authorities have designed, during last years, different emission abatement strategies (use of cleaner fuels for domestic heating, limitation of the circulation for non-catalysed vehicles during colder seasons, etc.). Despite such efforts, PM_{10} concentrations overcome air quality standards in large portion of the territory, claiming for further actions on anthropogenic emissions in order to meet the levels prescribed by EU directives. In this perspective, modelling systems based on state-of-science chemical transport models (CTMs) are fundamental elements in air quality management. In fact, they allow to investigate the contribution of emission sources (Cheng et al., 2007), transport and chemistry on pollutants behaviour at different

* Corresponding author. Tel.: +39 02 27007255; fax: +39 02 25708084.
E-mail address: c.silibello@aria-net.it (C. Silibello).

1364-8152/$ - see front matter
doi:10.1016/j.envsoft.2007.04.002

scales (from the local to the regional scale), to investigate source–receptor relationships, to effectively integrate the information provided by air quality networks especially in areas not covered by measurements and to develop emission control strategies (Mediavilla-Sahagún and ApSimon, 2006). Different modelling exercises have been focused on the area (Angelino et al., 1993; Silibello et al., 1998; Finzi et al., 2000; Dosio et al., 2002; Hammer et al., 2002; Martilli et al., 2002; Spirig et al., 2002; Gabusi and Volta, 2005; Decanini and Volta, 2003; Decanini et al., 2003; Carnevale et al., 2006) and experimental studies (Alicke et al., 2002; Baltensperger et al., 2002; Dommen et al., 2002; Neftel et al., 2002; Putaud et al., 2002; Stutz et al., 2002; Thielmann et al., 2002). These studies have confirmed the complexity of factors influencing air quality in Milano and have also evidenced the possibility of simulating the observed levels, providing that CTMs are fed by realistic data. The work presented here is part of research projects on air quality funded by Lombardia Region and it is devoted to the application of a modelling system on a winter PM_{10} episode in the Milano metropolitan area and other nearby areas. This application has been considered a necessary step to be undertaken for the analysis of emission control strategies. Section 2 describes the area under study and the episode selection criteria, Section 3 describes the modelling system and Section 4 summarises the modelling results and their comparison with monitoring data. Finally, Section 5 summarises the major steps followed in the modelling process.

2. The study area

Milano, the most relevant city in Lombardia, is one of the largest metropolitan areas in Western Europe. Since 1970, the core municipality of Milano has lost more than 400,000 residents, nearly one-quarter of its population, while the suburbs have been continuously growing. Depending upon the definition, Milano metropolitan area has between 4,000,000 and 6,000,000 residents, 1,250,000 of whom live in the core municipality. Most of the suburban development is spread to the North, West and East of the city, while in the South a large portion of the land is dedicated to agricultural activities. One of the side-effects of suburban growth is the increase of vehicular traffic from surrounding area towards the centre (more than 600,000 vehicles enter in the urban core during weekdays) that, coupled with recurrent thermal inversions and low winds, results in poor air quality episodes concentrated during winter months. These problems have induced the Regional authorities to define the "Milano–Como–Sempione critical area" (see Table 1 for related statistical information) for which action plans have to be taken in order to improve the air quality in accordance to the Framework Directive 96/62/EC. That area, which includes the Milano metropolitan district and follows the route of two major highways that connect Milano with Switzerland and Milano with Varese through highly populated neighbourhoods, is the target domain of this modelling study (Fig. 1). In terms of yearly averaged concentrations, the emission abatement strategies adopted during the last years led to a decrease in CO, SO_2 and NO_2 levels, but no appreciable effects on PM_{10} and ozone concentrations (Fig. 2) have been detected. Moreover, the air quality standards for PM_{10} (continuous measurements are only available from year 1998) are overcome in large portion of the territory, with an interannual variability that most likely depends on meteorological factors (see Fig. 3). These experimental evidences claim for the implementation of further emission control strategies addressed to the reduction of the exposure to PM levels, both at local scale and up to the basin scale of the entire Po Valley. The impact of planned strategies needs to be carefully analysed also by means of emission inventories, meteorological and dispersion models, as suggested by EU air quality directives. In this perspective a significant wintertime PM_{10} episode occurred during 17–23 December 2001 over whole Lombardia has been considered. PM_{10}, CO and NO_2 concentrations measured at Milano (Verziere) and Meda sites (Fig. 4) show the relevance of the episode. It is interesting to observe the different behaviours of PM_{10} in the two sites: in the traffic site directly influenced by nearby vehicular emission (Meda), PM_{10} concentrations are highly correlated with CO ones, while in the urban background site (Milano-Verziere) the correlation is evident between PM_{10} and NO_2; these differences confirm the awaited response of PM_{10} mass to both vehicular emissions and stationary sources, especially when secondary particles are involved (Harrison et al., 1999). The episode is meteorologically characterised by a persistent anticyclonic pressure field, with warmer air between 700 and 500 hPa, leading to isothermal profiles that inhibit the vertical dispersion of pollutants present in the lower troposphere. The situation is worsened by the persistence of very low wind conditions. Temperature vertical profiles from soundings taken at Milano-Linate airport during the episode and ground-based wind direction and direction recorded at Milano-Juvara urban site during the whole December 2001 are presented in Fig. 5.

Table 1
Milano–Como–Sempione critical area data

Zones	Population	Area [km^2]	Population per km^2
Milano	2,440,000	581	4200
Como	460,000	236	1950
Sempione	465,000	241	1930
Milano metropolitan area (continuously built up area)	3,685,000 (similar to Atlanta, Barcelona, Sydney)	1520 (similar to Kansas City, Mexico City, Montreal)	2420 (similar to San Francisco, Brussels, Sydney)

3. Methodology

To simulate the selected episode over the target domain (Fig. 1, 70 × 70 km^2 with a resolution of 1 km), the modelling system outlined in Fig. 6 has been adopted. The system is based on *F*lexible *A*ir quality *R*egional *M*odel (FARM; Carmichael et al., 1998; Calori et al., 2005; De Maria et al., 2005; Silibello et al., 2005), a three-dimensional Eulerian chemical transport model. Physical and chemical processes influencing the