A one-year application of the Veneto air quality modelling system: regional concentrations and deposition on Venice lagoon

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Abstract: The Po valley is one of the most polluted area in Europe regarding ozone and PM10. To support policy-makers to implement programmes to reduce air pollution, the Veneto Region Environmental Protection Agency has set a state-of-the-art modelling system. Comparison between model results and measurements illustrates a fairly good agreement for NO_2 annual mean concentration and deposition levels and daily maximum O_3 levels. The disagreement for PM10 results suggests the need of further improvements in the emission inventory and the meteorogical pre-processing. The aim of this application is to estimate atmospheric loads on the Venice lagoon through the model's deposition computation.

Keywords: model assessment; northern Italy; NO_2; O_3; PM10; deposition.

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1 Introduction

Local topography and meteorological conditions over the Po valley, as well as natural and anthropogenic emissions, make this area one of the most polluted in Europe especially regarding the concentrations of secondary pollutants such as ozone and PM10. The Veneto region covers the eastern part of the Po valley and is bounded by the Alps to the north and the Adriatic Sea to the east. Trans-boundary pollution exchange with the Lombardy and Emilia-Romagna regions in the west and south direction, respectively, could play an important role for the local air quality state. The Veneto Region Council financed the SIMAGE project with the aim of protecting the environment of the Venice lagoon. Under the SIMAGE project, a state-of-the-art air pollution modelling system has been implemented to assess the pollution and deposition levels in the Venice Lagoon considering all source of local emissions as well as trans-boundary pollution.

The modelling system has been run for one year starting from 1 July 2004. The concentration and deposition fields of the regulated primary and secondary pollutants and nutrients have been computed and compared with measurements from air-quality monitoring stations and bulk deposition campaign measurements.

2 Modelling system set-up

The Veneto Region modelling system for air quality assessment comprises an integrated Bottom-Up and Top-Down emission inventory. The national Top-Down emission inventory (Liburdi et al., 2004) is disaggregated at province level in space and at activity level on emission sources (SNAP'97 nomenclature – http://reports.eea.europa.eu/). This inventory has been further disaggregated to the municipality level (Gnocchi et al., 2005, 2006) carefully choosing proxy variables tailored for each sector. Emissions are then distributed over a regular grid based on the land-use, i.e., residential combustion is distributed over urban areas. Furthermore, emissions are chemically disaggregated and temporally modulated considering local data from each emission sector (Maffeis, 2002).

The major point sources for emissions belonging to industrial SNAP sectors (1, 3, 4, 6 and 9) have been collected in a Bottom-Up inventory. Hence, a mixed Top-Down and Bottom-Up inventory (Gnocchi et al., 2005, 2006) is used in the modelling system. The annual emissions and the share of the SNAP sectors are presented in the self-explanatory (Table 1).

CALMET model (Scire et al., 2000) is used to produce the meteorological input fields. CALMET blends together data coming from 32 surface stations (of which nine are synoptic), one off-shore station and three radio-sounding stations and provides the chemical model CAMx (Environ International Corporation, 2004) with the hourly temperature field, the horizontal wind and the vertical diffusivity at every grid cell. Furthermore, pressure and water vapour content are directly computed by interpolation of radio-soundings data whereas an ad-hoc processor interpolates synoptic cloud data and produces three-dimensional cloud input fields. The meteorological processor has been tuned to best represent the meteorological fields in the domain of interest (Sansone et al., 2005; Pernigotti et al., 2005).

Table 1 Regional emission inventory and share of the main emission sectors

Pollutant	*Emissions* (tons/yr)	*Sector 1 energy* (%)	*Sector 3 industry* (%)	*Sector 6 solvents* (%)	*Sector 7 road transport* (%)	*Sector 8 other transport* (%)	*Others heating, waste, nature* (%)
Primary PM10	15,850	9	19	0	29	15	28
VOC	130,457	0	1	42	34	8	15
Nox	128,518	18	14	0	44	14	10
SO2	110,542	80	13	0	1	1	5

The domain covers most of the Veneto region on a 50×42 horizontal mesh with 4×4 km^2 resolution. Vertically, CALMET is initialised with 10 levels from the surface to 3000 m height. On the same grid, CAMx is used for the dispersion of primary and photochemical compounds, primary and secondary aerosol. The chemical mechanism used is the Carbon Bond IV (Gery et al., 1989) with heterogeneous chemistry.

Boundary and initial conditions are given by CHIMERE output from Prev'air system (http://prevair.ineris.fr) with 0.5° of resolution (roughly a 30×50 km^2 mesh). The concentration of the species at the boundaries is updated every hour. Moreover, a conversion table has been created to translate CHIMERE species into CAMx species.

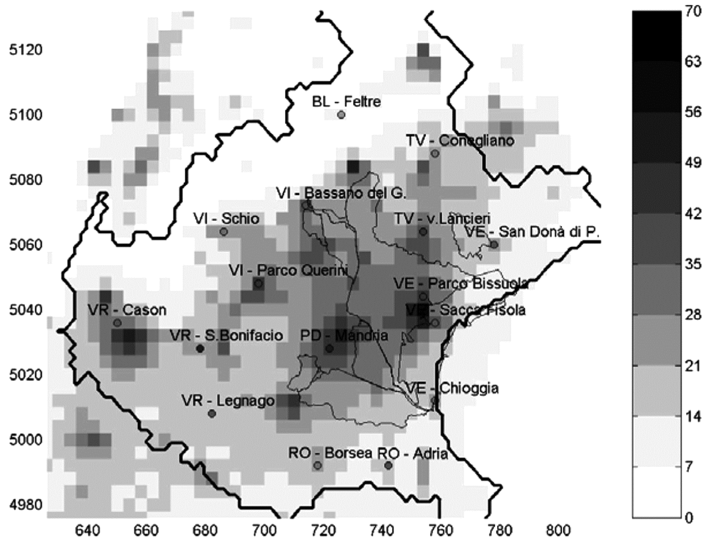
Initial conditions consist of a single 3D field of the species modelled by CAMx while the top condition for each chemical specie is constant both in space and in time.

Ozone column integrated concentration levels and atmospheric turbidity are downloaded from the NASA website (http://aeronet.gsfc.nasa.gov/data_menu.html). A five-dimensional table of photolysis rates is obtained from the TUV model for each of the six photochemical reactions included in CAMx chemical mechanism.

3 Model performance

In this section, we focus the discussion on the pollutants that are critical for the air quality in the Veneto region namely nitrogen oxide, ozone and particulate matter whereas the deposition data considered are sulphates and nitrates. The model performance is evaluated by comparing the data from monitoring stations and the model results in 16 points of the domain for gas species (visible in Figures 1 and 2), 11 points for particulate matters and three points near the Venice Lagoon for the deposition. As a term of reference, the monitoring station "VE – S.Fisola" is positioned in the Venice Island, in the middle of the Lagoon. The lagoon itself is outlined by the thin black line surrounding the "VE – S.Fisola" station.

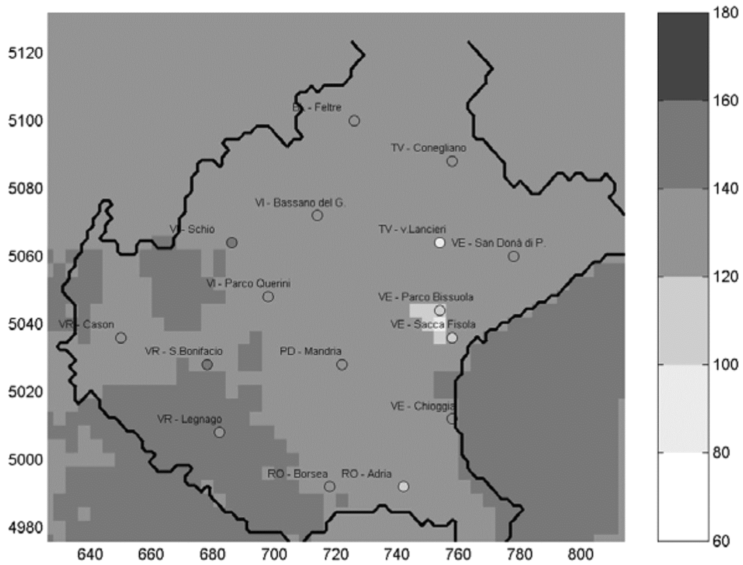
Figure 1 Annual mean concentration of NO_2 ($\mu g/m^3$) as in the model simulation superimposed to the measurements (dots). The grey tone inside the dot reflects the same quantity calculated for the model output (i.e., annual mean NO_2) using the monitoring station data. The coordinate system is UTM (km)



3.1 Ground-level concentrations

The annual average concentration of NO_2 is very well captured in the space by the modelling system (Figure 1). The hot spots for NO_2 are located in the urban areas with a peak concentration near the Venice lagoon owing to also intense industrial and port activities. The maximum summer ozone concentrations (Figure 2) generally occur above the sea and in the western part of the domain with minimum concentrations over the industrial area in Venice, owing to O_3 consumption by 'fresh' nitrogen emissions. Again, the spatial variability and the absolute value of mean daily maximum concentration are well reproduced by the model (Figure 2).

Figure 2 Daily maximum O_3 concentration (μg/m^3) averaged for five summer months July–September 2004 and May–June 2005 superimposed to the measurements (dots). The grey tone inside the dot reflects the same quantity calculated for the model output (i.e., daily maximum ozone averaged for five summer months) using the monitoring station data. The coordinate system is UTM (km)



In terms of temporal modulation of hourly concentration, NO_2 has a relatively weak correlation for some stations. Most of the correlation coefficients lay between 0.4 and 0.6. One of the reasons can be due to the temporal modulation of the diurnal mixing and emissions. In the real world, the hour of peak emission changes between summer and winter owing to the shift of human habits.

On top of that, the modelled mixing rate has an abrupt transition at sunrise and sunset owing to the change in the mixing schemes implemented in CALMET at the transition hours. The abrupt change in the mixing can lead to an abrupt change in the ground-level concentration particularly evident for primary species with sharp horizontal gradient in the emissions such as NO_x and SO_2. This temporal shift has a lesser impact on secondary species like ozone as shown by the high degree of correlation between the measurements and the model results (Table 2).

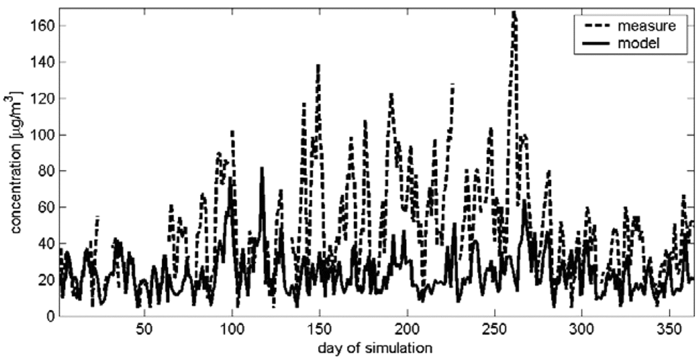
In terms of PM10 daily average, the model underestimates the ground-level concentration in wintertime (Figure 3). The underestimation is on an average around 50%. A number of reasons are responsible for the underestimation, some of them common to state-of-the-art particulate models (another Italian example of state-of-the-art chemical modelling is given in Deserti et al., 2006): lack of processes resolved by the chemical scheme, low-level concentration in the boundary conditions, lack of emission processes as re-suspension of particles from soil, roads and sea spray.

Table 2 Correlation coefficients between measurements and model estimate at 16 (11) sites in the Veneto Region for hourly value (NO_2 and O_3) and daily average (PM10)

Station	*VE-P.Bissuola*	*VE-S.Fisola*	*VE-Chioggia*	*VE-San Donà di P.*	*VI-Parco Querini*	*VI-Schio*	*VI-Bassano del G.*	*RO-Borsea*
NO_2	0.50	0.48	0.60	0.58	0.54	0.36	0.40	0.63
O_3	0.73	0.76	0.84	0.85	0.83	0.78	0.76	0.84
PM10	0.65	0.68	0.49	0.51	0.70	0.67	0.68	0.62

Station	*PD-Mandria*	*VR-Cason*	*VR-S.Bonifacio*	*VR-Legnago*	*BL-Feltre*	*TV-Lancieri*	*TV-Conegliano*	*TV-Mansuè*
NO_2	0.52	0.49	0.44	0.38	0.34	0.54	0.30	0.37
O_3	0.80	0.73	0.83	0.82	0.87	0.74	0.81	0.60
PM10	0.46	0.56	0.45					

Figure 3 PM10 daily mean concentrations at VR-Cason station (Rural Background) in the western corner of the domain as reported by the monitoring station (dashed line) and the model (solid line). The simulation starts the from 1 July 2004



In summertime, the enhanced vertical dispersion of the pollution owing to high surface heat fluxes dilutes the ground-level concentrations and renders the above-described model deficiencies negligible. In the wintertime, the residence time of the pollution in the atmosphere increases with respect to the summertime owing to low-level thermal inversions that can reside for several hours up to few days. In these conditions, the model deficiencies become evident.

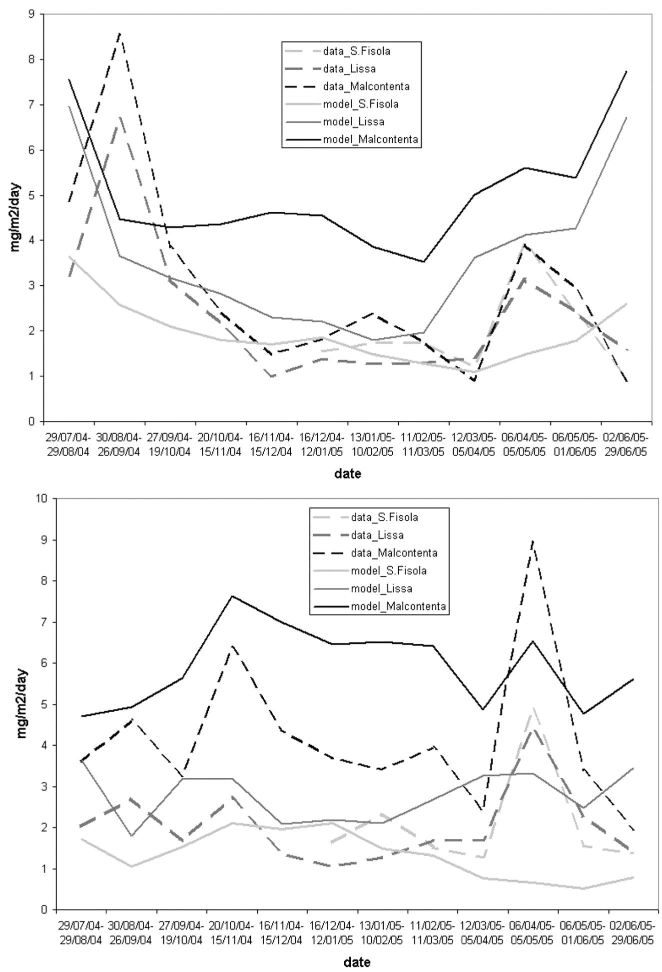
Despite the lack of processes and input data, PM10 time variability is sufficiently well represented in some measuring sites and can reach correlation coefficients as high as 0.7 (Table 2). Correlation below 0.5 is calculated for the stations: VE-Chioggia, PD-Mandria and VR-S.Bonifacio. There is no commonality among those stations hence the reasons for such poor correlations between measurements and model output differ. VE Chioggia is placed near the sea where the sea salt component may be relevant at times and influence the correlation. In the simulation presented here, the sea salt is not considered. PD-Mandria and VR-S.Bonifacio are an urban background and a sub-urban background station, respectively. The position of the station with respect to the nearest roads as well as the performance of the meteorological model in those areas certainly plays a major role in determining the PM10 fluctuations in the model.

3.2 Deposition data

Three bulk deposition collectors have been placed near or inside the Venice Lagoon. S.Fisola site (SFI) inside the lagoon (Figure 1), Lissa (LIS) is inside the urban area and Malcontenta (MAL) downwind the industrial area. The distance between each site is roughly 10–15 km. Six monthly campaigns in S.Fisola and 12 in Lissa and Malcontenta sites have been performed. These measurements have been compared with the model simulation.

Figure 4 illustrates the comparison between the daily average deposition of sulphur (Figure 4, top) and nitrogen (Figure 4, bottom). The dashed lines indicate the measurements and the solid lines indicate the model estimates. The chemical species considered for the calculation of nitrogen depositions are the gas pollutants NO, NO_2, NH_3, HNO_3, organic nitrate and the nitrate and ammonium component of the particulate matter. For sulphur deposition, in addition to the sulphate particulate, the gas compounds considered are SO_2 and H_2SO_4.

Figure 4 Sulphur (top) and nitrogen (bottom) daily mean deposition in three sites (dashed lines) for 12 monthly campaigns (*x* axis) compared to the model estimate (solid lines)



Dissolved gases and deposited particulate matter have been normalised to the molecular weight of sulphur and nitrogen for a fair comparison among the experimental and numerical data. The model captures both the mean values and the spatial variation of the bulk deposition for both sulphur (particularly) and nitrogen (to a lesser extent). The MAL site, in fact, presents a higher deposition compared with the other two sites as shown both in the measures and in the model (Figure 4, top). However, in the nitrogen case, the deposition is similar in the three measurement sites while the model estimates a higher deposition in MAL site relative to the other two locations (Table 3).

Table 3 Twelve months average deposition (six months for S.Fisola) in micrograms/m^{-2}/day

Deposition ($mg/m^{-2}/d^{-1}$)	*Sulphur SFI*	*Sulphur LIS*	*Sulphur MAL*	*Nitrogen SFI*	*Nitrogen LIS*	*Nitrogen MAL*
Measurements	2.1	2.0	4.2	1.9	2.4	3.0
Model	1.1	2.8	5.9	1.7	3.6	5.1

The atmospheric load of nutrients on the Venice Lagoon is estimated in two ways: one way uses the average deposition of the experimental data from each monitoring station; the second way employs the model estimate. The experimental method leads to a nutrient load estimation by the atmosphere to the Lagoon of 372 (420) tons/year of total nitrogen (sulphur) while the model accounts for 210 (201) of the same quantity. The experimental method overestimation with respect to the model is most likely due to the lack of deposition measures inside the Lagoon.

4 Conclusions

The Veneto Region modelling system for air quality has been tested against measurements along one year. Considering the current scientific knowledge in pollution modelling, a satisfying level of correlation between model and measurements for all pollutants has been reached. Furthermore, the model estimates a reasonable magnitude of the deposition field for sulphates and nitrates.

Yet, some challenges are still open to drive future improvements: O_3 daily maximum in summer is underestimated, night-time hourly NO_2 and PM10 concentration level are generally underestimated; the spatial variability in the deposition field for the Venice Lagoon area is somewhat overly marked in the model with respect to the measurements.

The annual simulation presented in this paper allows for the estimation of the atmospheric contribution of the pollution load on the Venice Lagoon that are useful for policy-makers and the decision process regarding regulation on nutrients load in the Venice Lagoon environment. Past estimation of atmospheric contribution based only on experimental data extended terrain sites deposition measures on Lagoon area, which instead on the base of model results has a lower deposition with respect to coast site. Furthermore, the modelling system could be used in the near future to assess the contribution of the various emission sources to the air pollution in this region and the relative contribution of the atmosphere with respect to the other means (water and soil) in terms of nutrients deposition in the Venice Lagoon. General improvements of model chain will regard: inventory completeness (particularly for PM), implementation of a prognostic meteorological model, sensitivity studies of model results.

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