Evaluation of industrial sources' contribution to PM10 concentrations over a coastal area

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Abstract

The analysis of air quality data in a monitoring site in the southern part of the Apulia region (south-eastern Italy) has shown that it exceeds the daily mean value of particulate matter with an aerodynamic diameter less than 10 μm (PM10) established by Italian regulations in force. In the neighbourhood of the site relevant power plants are present. The aim of this study is to evaluate the contribution of these industrial sources using the RAMS [1]-CALMET [2]-CALPUFF [3] modelling system.

Results show that the contribution of industrial sources is significant to the total pollution, but such a contribution explains only a small percentage of the PM10 measured in the site. The fallout of primary particulate matter has turned out very low, while the contribution of the secondary one, related mostly to SO_x and NO_x emission, has been higher. Meteorological and dispersion simulation indicate that the high values registered in the site can be attributed to a local source present in the little town where the station is placed and are representative of a very small area.
Keywords: industrial sources, particulate matter, wind calm.

1 Introduction

The atmospheric suspended particulate matter represents one of the most well-known environmental problems in the industrial countries, such as Italy. A recent study of the Italian Committee for Air Pollution [4] analyzed the characteristics of particulate pollution, especially that with an aerodynamic

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diameter less than ten micrometer (PM10), which represents the most dangerous fraction for human health and it is regulated by National and European law.

Anthropogenic prime sources of PM10 are combustion, vehicular traffic and industrial processes. Concentration levels of airborne pollutants within a city depends on many factors of which the most important are the strengths and the distribution of local pollution sources, presence of distant pollution sources that have impact on the city, and meteorological and topographical conditions of the area. Moreover, it must be noted that particulate matter doesn't come exclusively from direct emission (called "primary"), but it forms through complicated chemical-physical mechanisms ("secondary") starting from gaseous elements such as nitrogen oxides (NO_x) and sulphur oxides (SO_x).

As emerged by the previously mentioned study, the contribution of secondary PM10 to the total concentration is relevant, such to be determining in the episodes of exceeding the daily mean value as established by Italian regulation in force (50 $\mu g/m^3$). This is why, in the presence of primary PM10 sources produced by combustion and gaseous precursors of secondary PM10, it's important to follow the plume evolution of both pollutants for better understanding the ground measurements of the air quality monitoring stations.

Specific studies should be carried out to evaluate environmental impact [5] of pollutants in the study area, due to a combination of causes: the presence of huge industrial plants, in particular power plants whose combustion processes gives rise to the emission of both primary and gaseous precursors of secondary particulate pollutants; emission of pollutants depends on combustion matter's quality and technology; transport, transformation and deposition of contaminants depends on regional climatic conditions.

The present work focuses on the study of PM10 concentrations registered in a coastal region and the relationship with the power plant emissions, in particular the contribution of secondary component to the total ones.

2 Description of the area

The investigated area is located in south-eastern Italy, washed by the Adriatic Sea on the eastern side and by the Ionian Sea on the western. It is long and narrow with a topography generally flat such to have a weak effect on the flow: the region is influenced along its entire coastal perimeter, mainly by complex sea-land breeze systems caused by the diurnal heating cycle.

Figure 1 shows the domain of interest: there is an Air Force meteorological station (MET1), a meteorological station belonging to the University of Lecce (MET2), and the monitoring site AQ1 situated in the small town of Torchiarolo, that measures both meteorological and air quality data.

This station is classified as a background industrial station, even if, compared with this classification, its location seems to be not so good: in fact it is located in a light sinking, close to the town in the W-SW direction, that creates a kind of barrier as well as being itself an emission source of pollutants.

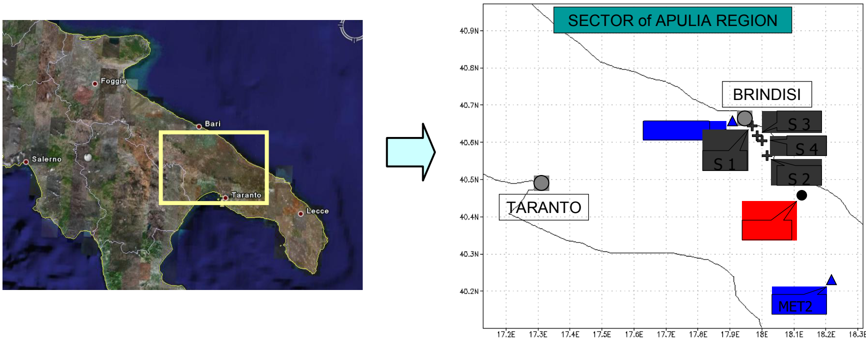

Figure 1: Study area; (on the right) black point is the AQ1 air quality station, the triangles are the meteorological stations of Air Force near Brindisi (MET1) and University of Lecce (MET2), and the crosses (S1/S4) are the industrial point sources.

The PM10 measurements carried out during 2005 in site AQ1 have shown they exceed the daily mean value, particularly in the winter season (Figure 2). In the area there some important industrial plants, in particular power plants.

They emit into the atmosphere primary fly ash particles and secondary aerosol which are carried and dispersed by atmospheric motion over a wide range, depending on the various meteorological parameters. In particular the gas-to-particle conversion process gives rise to considerable volumes of highly reactive secondary particulate pollutants after the oxidation of sulphur and nitrogen oxides. Bearing in mind these processes, in power plants with high SO_2 and/or NO_x emission, the generation of secondary particulate could reach up to a few orders of magnitude higher than those of primary particulate emissions, in mass per year.

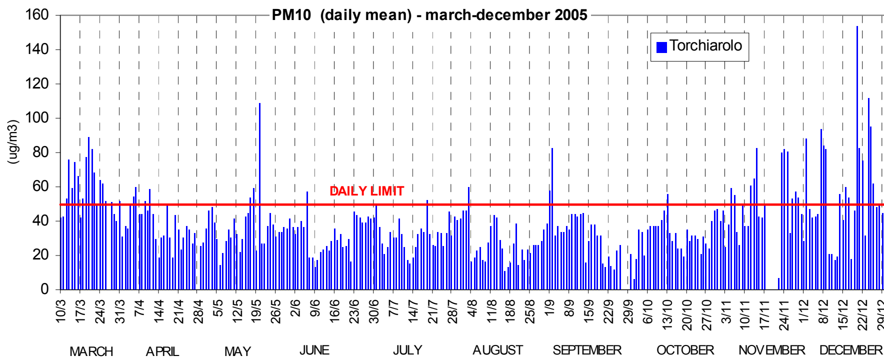

Figure 2: Daily mean concentrations of PM10, measured at site AQ1 during 2005.

In Table 1 the geometrical characteristics and the emissions of the industrial sources considered in the case studies are summarized.

Table 1: The geometrical characteristics and the emissions of the industrial sources.

INDUSTRIAL SOURCES	STACK HEIGHT (m)	SO_2 (t/a)	NO_x (t/a)	PTS (t/a)	FUEL
S1	60	2.238	3.272	152	COAL
S2	200	11.860	9.970	1.052	COAL
S3	50	3.600	1.915	133	OIL
S4	53	1,6	26	1,1	WASTE

Due to the combination of synoptic circulation regime and local features, meteorology of the area is quite complex: the wind field is characterized by a great temporal variability and all the area is subject to complex land-sea-land circulation system.

Figure 3 shows the wind roses calculated in the meteorological station MET1 (Figure 3(a)) and MET2 (Figure 3(b)), and station AQ1 (Figure 3(c)), all equipped with instruments for measuring wind intensity and direction. A prevailing NW component is observed in all stations; in the first two (MET1-MET2) a strong S-SE component is also evident, while in the third (AQ1) the wind direction is much more distributed.

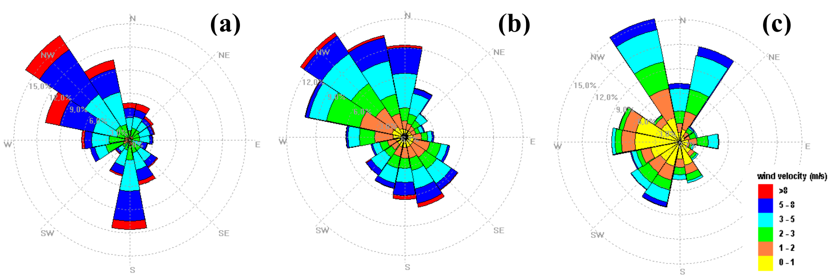

Figure 3: Wind roses measured in the MET1 station (a), in MET2 station (b) and in AQ1 station (c).

At AQ1 station the wind intensity of about 0-1 m/s represents almost the 40% on the total wind rose, especially along the western direction, while the percentage of wind calm is about 24%. On the contrary, the meteorological stations MET1 and MET2, even keeping almost the same direction, have a calm percentage from 1% to 9%. By comparing AQ1 station with the other two, it is evident that the houses all around the monitoring site represent a kind of shield to the anemometer placed in the station.

The high number of calms has important consequences on the distribution of pollutants that arrive and develop there.

3 Modelling set up

The modelling system includes two meteorological models, RAMS and CALMET, and a dispersion model, CALPUFF. This model cascade suits quite well in describing specific situations with topographical and meteorological unhomogeneities [6], such as sea breezes, with computational domain from tenth of meters to hundreds of kilometers, times of average from hour to year, point sources, presence of inert pollutants or characterized by linear chemical conversion and removal processes.

The meteorological prognostic model RAMS (Regional Atmospheric Modelling System), developed at Colorado State University, is able to reproduce local circulation by means of a grid computation nesting, with a growing resolution. It contains an atmospheric model, which performs the actual simulation and a data analysis package which prepares initial data for the atmospheric model from observed meteorological data. The atmospheric model is constructed around the full set of primitive dynamical equations, which govern atmospheric motions. The RAMS model in this study was initialised and driven using the data from the European Centre for Medium-Range Weather Forecasts (ECMWF), updating fields every six hours; it has ran with a grid configuration of 3 nested grids, as shown in Figure 4, able to simulate meteorological driving forces at different spatial-temporal scales [7].

CALMET (CALifornian METeorological model) is a meteorological model which includes a diagnostic wind field generator containing objective analysis and parameterized treatments of slope flows, kinematical terrain effects, terrain blocking effects, a divergence minimization procedure, and a micro-meteorological model for overland and over water boundary layers.

CALPUFF (CALifornian PUFF model) is a non-steady-state Gaussian puff model containing modules for complex terrain effects, over water transport, coastal interactive effects, building downwash, dry and wet pollutant removal, and simple chemical transformation. It is designed to use meteorological fields provided by CALMET and time-dependent source and emission data. It produces one-hour averaged ground concentrations for the simulated chemical elements.

It is particularly suggested in estimating primary pollutant concentrations, but it contains a module that treats, in a simple way, some reactions of first order and that consists of a five species' scheme (SO_2, SO_4, NO_x, HNO_3, NO_3) based on the chemical mechanism MESOPUFFII [8]. The choice of this model is justified by the short availability of emission data, especially related to the speciation of particulate matter.

The characteristics of the modeling system are summarized in Table 2.

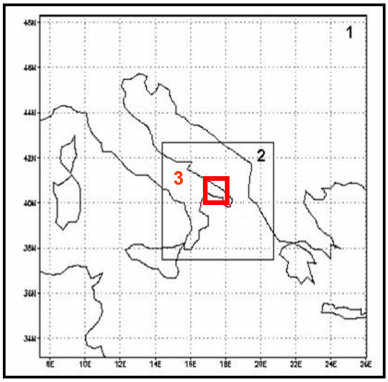

Figure 4: Grid structure for the simulations.

Table 2: Set up of modelling system.

MODELLING SYSTEM	RAMS	CALMET	CALPUFF
Grids	Grid 1: 26x26x25 - Δx=Δy=36 km Grid 2: 30x30x25 - Δx=Δy=9 km Grid 3: 50x50x25 - Δx=Δy=2 km	Grid 3: 50x50x10 Δx= Δy=1km	Grid 3: 50x50x10 Δx= Δy=1 km
Options	Meteorological updating fields from ECMWF	Interpolation of prognostic wind field. No-obs option	Chemical mechanism MESOPUFF

Two representative cases have been chosen that are characterized by the meteorological condition in which AQ1 station is downwind to the emission sources for some hours and it measures those exceeding the daily mean value of PM10. In Table 3 the scheme of case studies is shown.

Table 3: Scheme of case studies.

CASE STUDIES	PERIOD
Case A	13-16 October 2005
Case B	11-14 November 2005

4 Results and discussion

To verify the capability of the models to reproduce meteorological features of the area a comparison between meteorological model results and measurements has been performed.

Figures 5 and 6 show comparisons of the observed and predicted wind speed and direction values, during the two case studies. For all the stations, a diurnal wind cycle with more or less pronounced variability is evident.

In both cases the model is able to reproduce in a realistic way the wind field: when wind flows from western sectors the data registered in AQ1 are less than the modelled ones, confirming the fact that this monitoring station is strongly influenced by the presence of houses all around in the western, south-western sides.

In addition, it must be kept in mind that comparisons between observations and model predictions are complicated by the fact that observations are point measurements, while model predictions are representative for a horizontal grid cell of 1000 x 1000 m.

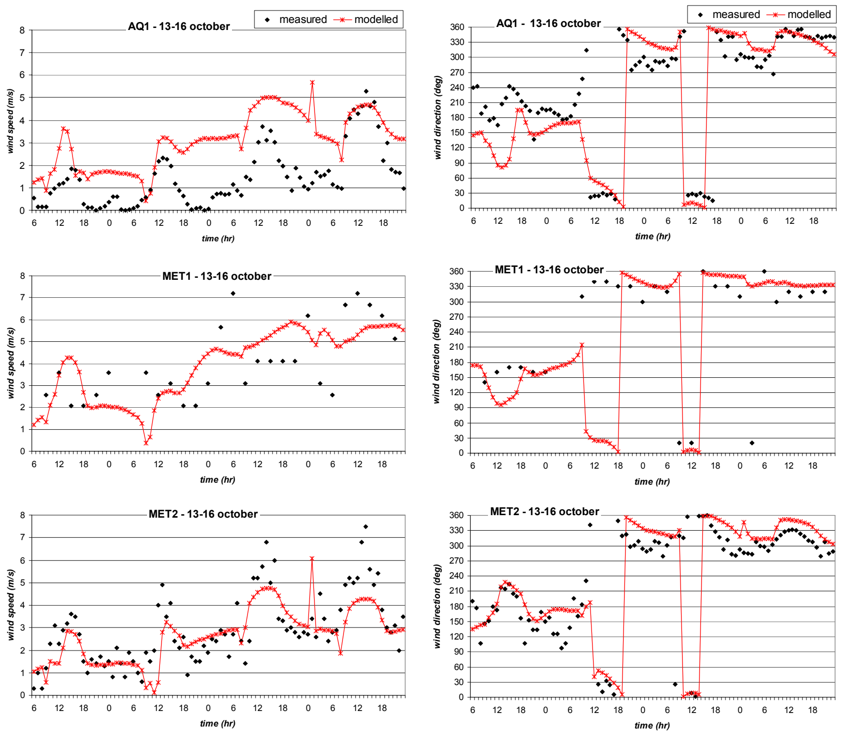

Figure 5: Evolution of modelled (line) and observed (point) hourly average wind speed (left) and direction (right) at the three stations, 13-16 October 2005.

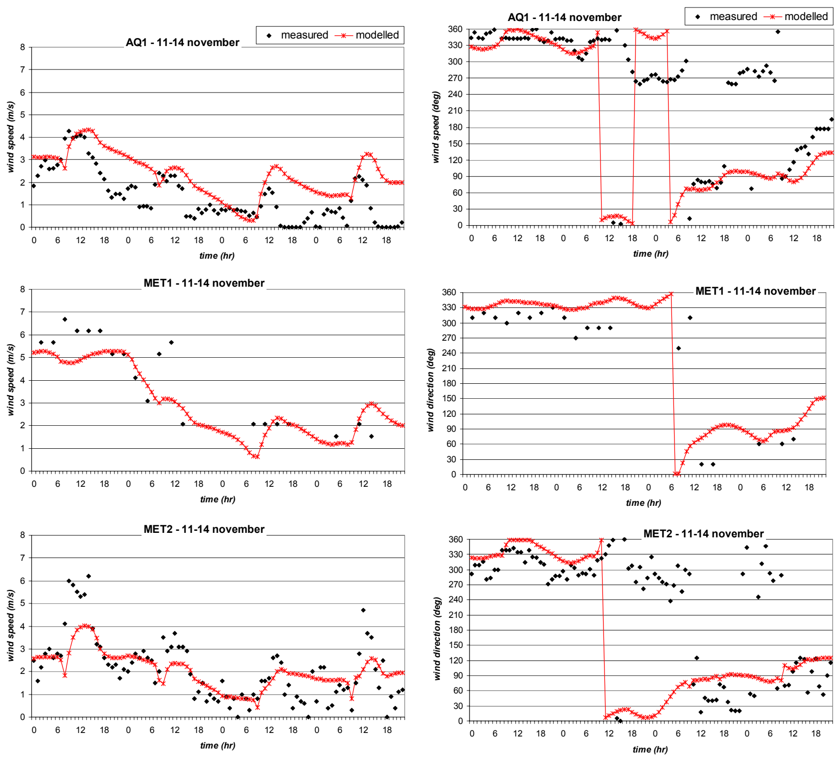

Figure 6: Evolution of modelled (line) and observed (point) hourly average wind speed (left) and direction (right) at the three stations, 11-14 November 2005.

In Figure 7 concentration fields (hourly averages at ground level) of primary (left panels) and secondary (right panels) particulate matter (as the sum of nitrates and sulphates) are shown for a specific day characterized by northern prevalent wind direction.

Fields are the sum of impact of each of the four industrial sources considered. The concentration values of secondary particulate seem to be always higher, sometimes of an order of magnitude, than the primary ones. The sum of primary and secondary components, averaged on 24 hours, is however well below of PM10 daily values measured during the two periods in station AQ1, representing just the 10-20%.

The lack of speciation data of both emitted particulate and other emission sources does not permit to estimate the contribution of other secondary components.

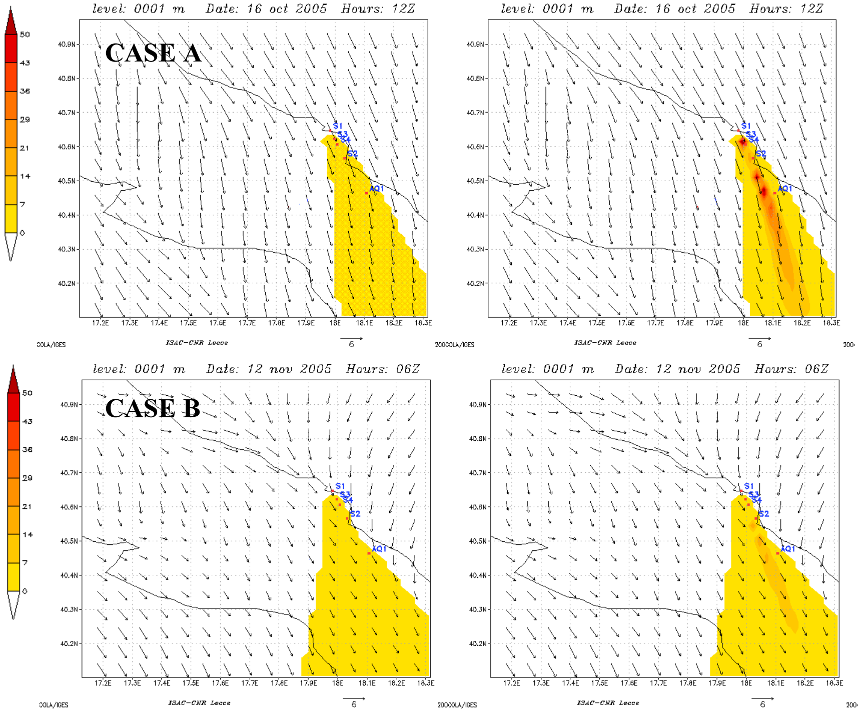

Figure 7: Ground concentration fields (µg/m^3) of primary (left) and secondary (right) PM10 for the two study cases.

5 Conclusions

In order to estimate the contribution of industrial sources exceeding the daily mean value of PM10 measured in the air quality monitoring station of AQ1, the RAMS-CALMET-CALPUFF modelling system has been used, for reproducing both meteorology and the dispersion of primary and secondary particulate matters. Modelling results have been compared with measured data. Results indicate that: i) the contribution of industrial sources to PM10 is present but it can explain just a little percentage of PM10 measured in AQ1 (10-20%); ii) the fallout of primary PM10 turns out lower than secondary component related mainly to the emission of SO_x and NO_x gaseous precursors; iii) the high number of calms registered in the station are strictly related to the particular positioning site of the station, so the high PM10 values can be related to emissions coming from the town and are not representative of the area.

Acknowledgements

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