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PERFORMANCE EVALUATION OF A MODELLING SYSTEM FOR AIR QUALITY FORECASTING AND AIR POLLUTION WARNING DURING PARTICULAR WINDY DAYS, IN A HIGHLY INDUSTRIALIZED AREA

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Abstract: This study evaluates the performance of a forecast modelling system of particular pollution events, named "windy days", due to the the aeolian resuspensions of particulate matter from the mineral stockyards of one of the largest steel plants in Europe located in Taranto (Southern Italy) industrial area. The modelling system is based on the meteorological prognostic model WRF and two dispersion models: the Eulerian photochemical model FARM and the Lagrangian particle model SPRAY. The system performs 72-hour air quality forecasts every day and produces concentration fields of main pollutants. SPRAY supplies the PM10 contribution from the mineral parks which are added to the background fields computed by FARM. The fugitive dust emission from the storage piles in the steelworks plant is dynamically modulated over time, depending on the wind speed, simulating the erosion caused by its action (EPA, 2006). Forecasted PM10 concentrations, performed during 2016, show a good agreement with observations, at all monitoring stations and confirm the improvements that can be obtained by combining and harmonizing two different modelling approaches to better describe the local pollutant distribution.

Key words: *Environmental impact assessment, Windy days, Air pollution management and decision support systems.*

INTRODUCTION

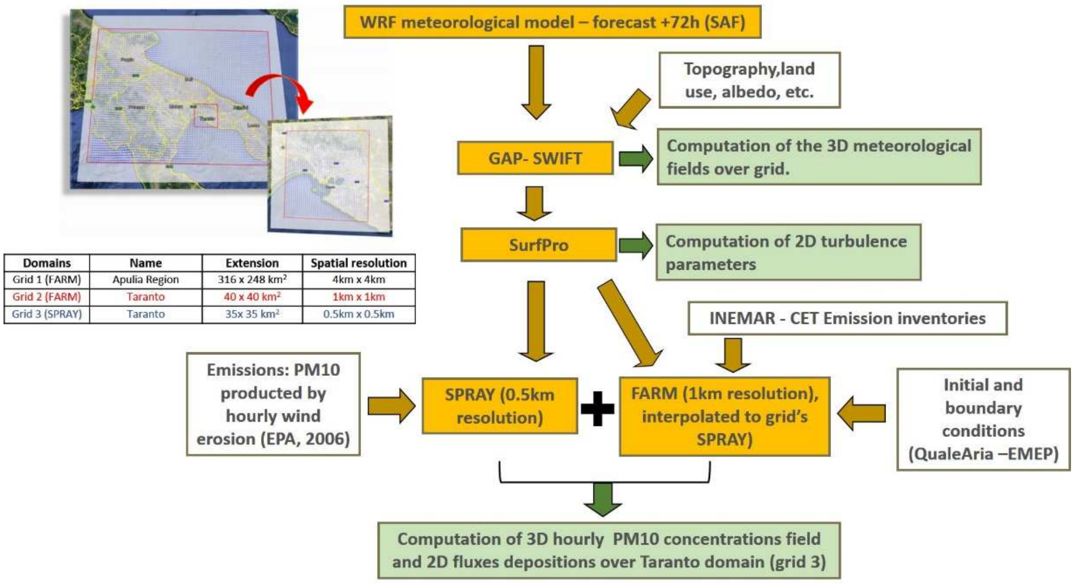
In the south-eastern part of Italy, Apulia Region, in proximity to the Taranto town (250,000 inhabitants), is located a large industrial site, consisting of an integrated steel plant (one of the largest in Europe), with extended mining parks which cover an area of 1.5 km^2.

The air quality monitoring in the Taranto municipality, conducted by the Regional Environmental Protection Agency (ARPA) of Apulia since 2005, showed that the population resident downwind the mineral parks of the steel plant is exposed to high PM10 levels during critical wind conditions (Trizio *et al.*, 2016). Previous air quality (AQ) assessments, performed with SPRAY model (Giua *et al.*, 2014; Vitali *et al.*, 2016), confirmed the relevance of local scale contribution from the industrial plants and, during the windy days, from steel plant mineral parks due to erosion processes. These facts induced the Apulia Government to adopt a Recovery Plan that includes a series of measures to be implemented during windy days events, identified by a criterion based on meteorological measurements, such as a more frequent and double wetting and filming of the mineral parks and a 10% reduction of PM10 emissions from diffusive and point sources (Regione Puglia, 2012).

According to the articles 14 and 18 of Legislative Decree 155/2010, ARPA Puglia has activated an adequate information and alert forecast system for the resident population through the web-site http://cloud.arpa.puglia.it/previsioniqualitadellaria/index.html. This system couples the Eulerian photochemical model FARM (Flexible Air quality Regional Model, Mircea *et al.*, 2014) and the Lagrangian particle model SPRAY (Tinarelli *et al.*, 1999) and includes the algorithm developed by EPA (EPA, 2006) to estimate dust emissions generated by wind erosion of open aggregate storage piles and exposed areas within industrial facilities. This work reports the analysis of the performance of the implemented forecast system, considering the 33 windy days occurred during the year 2016.

FORECAST MODELLING SYSTEM

The modelling system is based on the meteorological fields provided by the Weather Research and Forecasting (WRF) model, a limited-range prognostic meteorological weather model, operated by the ARPA Puglia SAF (Servizio Agenti Fisici) service, which provide 72hr forecasts on the entire regional territory with a spatial resolution of 4km. These fields are provided to the two dispersion models through the GAP-SWIFT SURFPro model chain.The Eulerian photochemical model FARM is applied to two nested domains including the Apulia region and Taranto area, with a spatial resolution respectively of 4 and 1 km (Figure 1). FARM is configured with an updated version of SAPRC99 gas-phase chemical mechanism (Carter, 2000), that includes PAHs and Hg chemistry, and the AERO3 modal aerosol module implemented in CMAQ model (Binkowski, 1999). The emissions are derived from the regional INEMAR inventory (http://www.inemar.arpa.puglia.it/) and the Territorial Emission Register of the Apulia region (http://www.cet.arpa.puglia.it). Initial and boundary conditions are provided by the QualeAria national air quality forecasting system (http://www.aria-net.it/qualearia/en/).



Domains	Name	Extension	Spatial resolution
Grid 1 (FARM)	Apulia Region	316 x 248 km^2	4km x 4km
Grid 2 (FARM)	Taranto	40 x 40 km^2	1km x 1km
Grid 3 (SPRAY)	Taranto	35x 35 km^2	0.5km x 0.5km

Figure 1. Diagram of the modelling system

PM10 concentration fields provided by FARM represent the background levels, due to the overall sources, to which is added the contribution from fugitive dust emissions from open aggregate storage piles in the steelworks plant, estimated by the Lagrangian model SPRAY at a resolution of 500 m. These emissions are estimated using a method derived from Section 13.2.5 of AP-42 Compilation of Air Pollutant Emission Factors (EPA, 2006) which allows to calculate accurate hourly emission from each park on the basis of the wind intensity data predicted by the meteorological sub-system. The total PM10 emissions considered for 2016 and related to the Taranto industrial area are almost 660 tons/year: 185 tons/year are the contribution from the aeolian algorithm and represent the 28% of the total industrial emission.

MONITORING STATIONS

To evaluate the modelling system performance for the year 2016, the PM10 predictions are compared with the observations, measured in nine air quality monitoring stations located in the Taranto municipality, managed by ARPA. The locations and the characteristics of the stations, distinguished by type as defined by conventional classification established by the Italian regulation, are shown in Figure 2 and Table 1. Figure 2 also shows the locations of the 8 mineral parks areas.

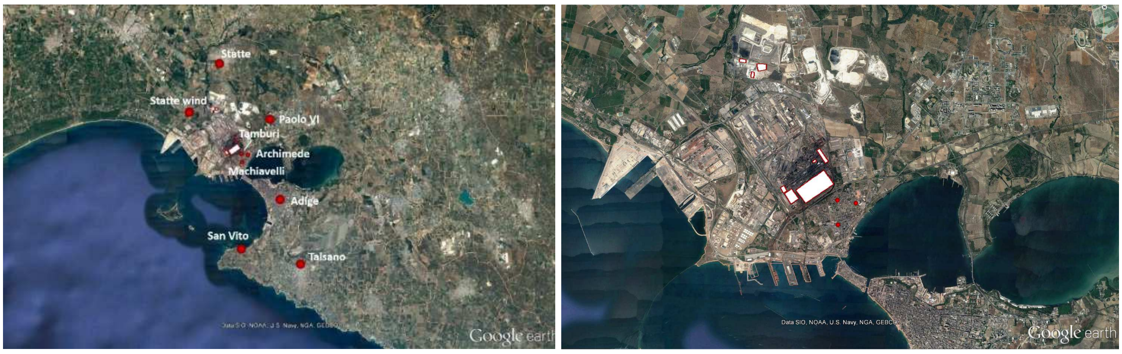


Figure 2. Location of monitoring stations (left) and mineral storage areas (blank areas) simulated by SPRAY (right)

Table 1. Monitoring station characteristics

Stations	X-UTM (km)	Y-UTM (km)	Type	PM10 (µg/m3)
Statte	686.5	4492.5	Suburban-industrial	daily
Statte wind	684.1	4488.4	Rural-industrial	bi-hourly
Paolo VI	690.9	4488.0	Rural-industrial	daily
Archimede	689.2	4485.0	Suburban-industrial	daily
Machiavelli	688.6	4484.4	Suburban-industrial	daily
Tamburi	688.6	4485.1	Urban-industrial	daily
Adige	691.9	4481.3	Urban-traffic	daily
San Vito	688.8	4477.1	Suburban-background	daily
Talsano	693.8	4476.0	Suburban-background	daily

RESULTS

Figures 3 show the comparisons between observed and modelled PM10 concentrations, considering the annual mean and the windy days mean. The analysis of these figures evidences that the contribution of mineral parks emissions is minimal in terms of yearly averages (very similar levels estimated by FARM and FARM+SPRAY chains) but is relevant during windy days. The improvement obtained due to the inclusion of mineral parks emissions, is particularly evident at the stations located near the industrial area (Tamburi, Machiavelli and Archimede; better agreement considering FARM+SPRAY PM10 levels).

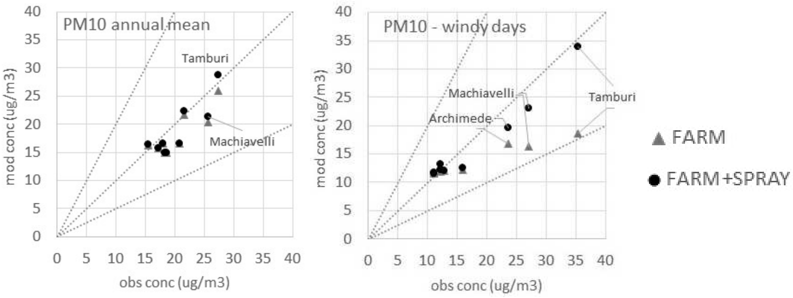


Figure 3. Scatter plot of observed vs modelled PM10 concentrations for FARM (triangle) and FARM plus SPRAY (circles) for annual mean (left) and daily mean of windy days (right).

The same considerations can also be applied to the scatter plots showed in Figure 4 (a-d), which report the comparison between observed and predicted daily PM10 averaged concentrations, during the 33 recognised windy day events, at four representative stations. The improvement introduced by the inclusion of fugitive dust emissions in SPRAY is more evident at Tamburi station, due to its proximity to the parks, and at Machiavelli station, because of its downwind position during windy days. The improvements are less evident at Archimede, located more to the west considering the prevailing wind directions during windy days (mainly from northwest), and Talsano, a background station where the effect of dilution of pollutants prevails.

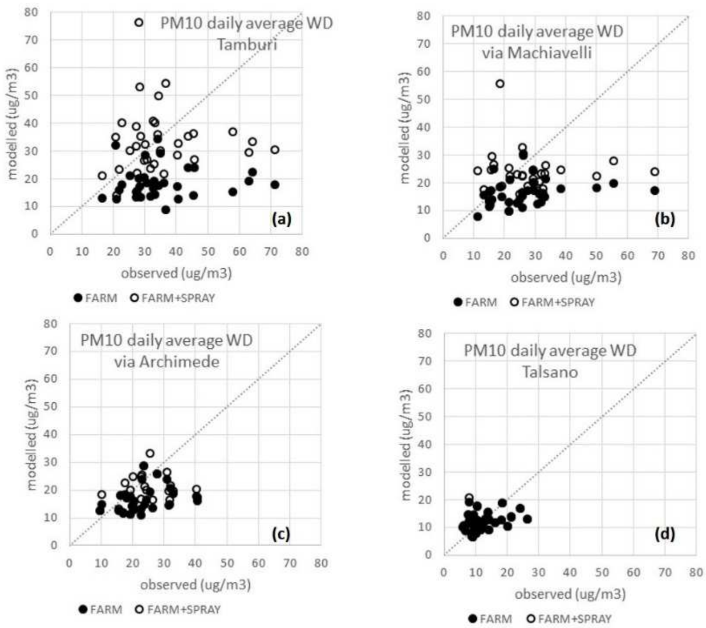


Figure 4. Scatter plot of daily averages during windy days of observed vs modelled PM10 concentrations simulated by FARM and FARM plus SPRAY, at four stations.

Table 2. PM10 forecast evaluation and skill scores analysis for the FARM model and FARM+SPRAY models considering all the stations in the Taranto area

PARAMETER	RANGE	FARM	FARM+SPRAY
BIAS [μg/m^3]	**(-∞,+∞)**	**-4.2**	**-1.2**
r	[0,+1]	**0.50**	**0.62**
RMSE [μg/m^3]	[0,+∞)	**10.6**	**9.2**
IA	[0,+1]	**0.54**	**0.76**
FAC2	[0,+1]	**0.86**	**0.91**
MFB	[-2,+2]	**-0.153**	**-0.003**
a		**10**	**40**
b		**3**	**12**
c		**60**	**30**
d		**208**	**199**
BIAS SCORE [%]		**18.6**	**74.3**
POD [%]		**14.3**	**57.1**
FAR [%]		**23.1**	**23.1**
ACC [%]		**77.6**	**85.1**

An assessment of forecast quality is performed computing some statistical parameters (Table 2). A perfect model would have RMSE=0, FAC2=1; r=1, IA=1 and MFB=0. The configuration FARM+SPRAY systematically shows better results. To evaluate how the integration of SPRAY model with FARM improves the capability to forecast high daily concentrations for PM10, the BIAS score, Probability of Detection (POD), the False alarm ratio (FAR) and the Accuracy (ACC) are computed. These skill scores have the following meaning: BIAS SCORE indicates whether the forecast overestimates or underestimates the number of exceedances, POD gives an idea of the fraction of the exceedances actually forecasted by the system, ACC measures the percentage of simulations that correctly reproduces exceedance and non-exceedance events and FAR is the fraction of forecasted exceedances that did not occur. The short term limit values imposed by the European Directive 2008/50/EC on air quality for PM10 (50 μg/m^3 daily average that should not be exceeded more than 35 times per year) cannot be used to identify the exceedance events, because they are rarely reached during the windy days events. According to Pay *et al.* (2014) the exceedance for this skill score analysis occurs when the daily forecasted/observed concentration is more than the 75th percentile of the observed concentrations for PM10 (23.1 μg/m^3).

The comparison of the skill scores for FARM model and FARM+SPRAY model confirmed the better capability of the latter to reproduce the exceedance events during the windy days.

CONCLUSIONS

In this study a performance evaluation of the forecast modelling system implemented by ARPA Puglia, for the year 2016 and for PM10, has been carried out during particular pollution events, named “windy days” which produce critical pollution effects on the city of Taranto. The system is based on two dispersion models: the Eulerian photochemical model FARM and the Lagrangian particle model SPRAY. The former estimates the background PM10 levels while the latter includes the contribution of local scale fugitive dust emissions due to the action of the wind on steel plant mineral parks.
The comparison of the PM10 average concentrations, measured during all windy days in 2016 at AQ monitoring stations, evidenced the ability of the modelling system to predict PM10 concentrations during such events. The integration of the Lagrangian particle model in the forecasting system, with its natural capacity to better describe the subgrid details of emissions, shows to be an indispensable element for a more realistic evaluation of total PM10 concentrations during windy days.

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