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# AIR POLLUTION IMPACT ASSESSMENT OF A COMPLEX INDUSTRIAL-URBAN AREA BY MEANS OF A LAGRANGIAN PARTICLE MODEL

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## ABSTRACT

Taranto hosts one of the most relevant industrial districts of Italy adjacent to an urban area. An impact assessment study has been conducted to evaluate the effect produced by the main emission sources on the local air quality. A local emission inventory has been developed taking into account industrial sources, traffic, domestic heating, fugitive and harbor emissions. A 3D Lagrangian particle dispersion model (SPRAY) has then been applied on the study area using meteorological data collected in seasonal field campaigns. 3D short term hourly concentrations have been calculated for both total and specific sources. Results show that the model is able to reproduce the measured $SO_2$ and $NO_x$ concentrations. Industrial activities are confirmed to be the main contributor to $SO_2$. Industry and traffic are the main responsible for $NO_x$ simulated concentrations. CO concentrations are found to be mainly related with traffic emissions, while primary $PM_{10}$ simulated concentrations seem to be linked with industrial and fugitive emissions. Model source contributions at selected monitoring stations predict on average 87% and 41% of industrial contribution to the total concentration of $SO_2$ and $NO_x$ respectively. Traffic emissions account for 45% of the total $NO_x$ and for 89% of the total CO concentrations on average.

**Key Words:** Air pollution, Industrial, Urban, Particle Model, SODAR.

## 1. INTRODUCTION

The city of Taranto is a populated-industrialized areas in Italy. In this city the typical urban emissions are superimposed on the industrial ones located in proximity of city. Among the industrial activities we can find: a large steel plant, being the biggest one in terms of both emissions quantity and extension of working areas; the third most important oil refinery in Italy; a cement facility. Other smaller emission sources can also be found in this territory mainly related with both the above industries and with the local economy. All these industrial activities use the harbor of Taranto to

download primary materials and to delivery final products. These tasks are often related with emissions of particulate matter. Ships also produce pollutants emission during wharf operations.
According to this frame, an air pollution impact assessment study has been conducted to provide information on the impact produced by the main emission sources on the local air quality and to quantify their contributions.

## 2. MATERIALS AND METHODS

### 2.1 Modeling system

The modeling system used in this study is composed by three codes: the MINERVE meteorological model, the SURFPRO turbulence pre-processor and the SPRAY Lagrangian particles dispersion model. SPRAY 3.0 (Tinarelli et al., 1994; Gariazzo et al., 2004) was used to reproduce the concentration fields generated by the pollutants emitted by the considered sources. SPRAY is a 3-D model able to simulate air pollution dispersion in the atmosphere in non homogenous and non stationary conditions. The 3D fields of wind and temperature have been calculated using the diagnostic code MINERVE (Aria, 2001) using a mass-consistent objective analysis scheme.
The random turbulent fluctuation of wind components ($\sigma_u$, $\sigma_v$, $\sigma_w$ and skewness $w'^3$) are used by SPRAY to determine the random motion causing the dispersion. They are calculated by means of parameterization codes (Hanna, 1982) based on scaling variables derived by SURFPRO code on the basis of the Monin-Obukhov similarity theory and surface energy budget evaluation (Van Ulden and Holtslag, 1985), starting from two dimensional arrays of surface parameters (albedo, Bowen ratio, $z_0$) and ground meteorological parameters given as input.

### 2.2 Field campaign description

Two field campaigns were conducted in winter and summer seasons to feed the model with real data and to validate the modeling results. To provide meteorological data to the modeling system, different stations were used (figure 1). Among the local monitoring network, five stations (Garibaldi, Peripato, Orsini, Paolo VI and Dante) were used, located both downtown and in the city neighborhoods. Pollutants concentration measurements were also carried out in the above stations. In addition three mobile laboratories were located in the studied area. A Mobile Meteorological Laboratory (MML) was placed in the harbor of Taranto. It calculates averaged values of the main standard meteorological data and turbulence parameters starting from data collected by sonic anemometers. Two mobile chemical-meteorological laboratory were located respectively, in a rural area of Palagiano about 30 Km west the city of Taranto, and in the urban area of Statte, nearly 15 Km north of Taranto. To get information on meteorological parameters in the east and north parts of the territory, two other meteorological stations were placed in the S. Giorgio and Monte Mesola villages. In order to provide upper air measurements, a SODAR/RASS system was used. Wind, turbulence and temperature profiles up to 400 m a.g.l were measured close to the MML station. Such data were completed by wind and temperature profiles up to 24 km collected every 6 hours at Brindisi by means of radiosoundings.


Figure 1. Satellite image of the study area with location of monitoring stations.

## 2.3 Emission inventory

The inventory set up for this study contains yearly emissions of five chemical species ($SO_2$, $NO_x$, CO, $PM_{10}$ and VOC) concerning the most significant anthropic activity sectors: industrial sources, road transport, domestic heating, marictime activity.

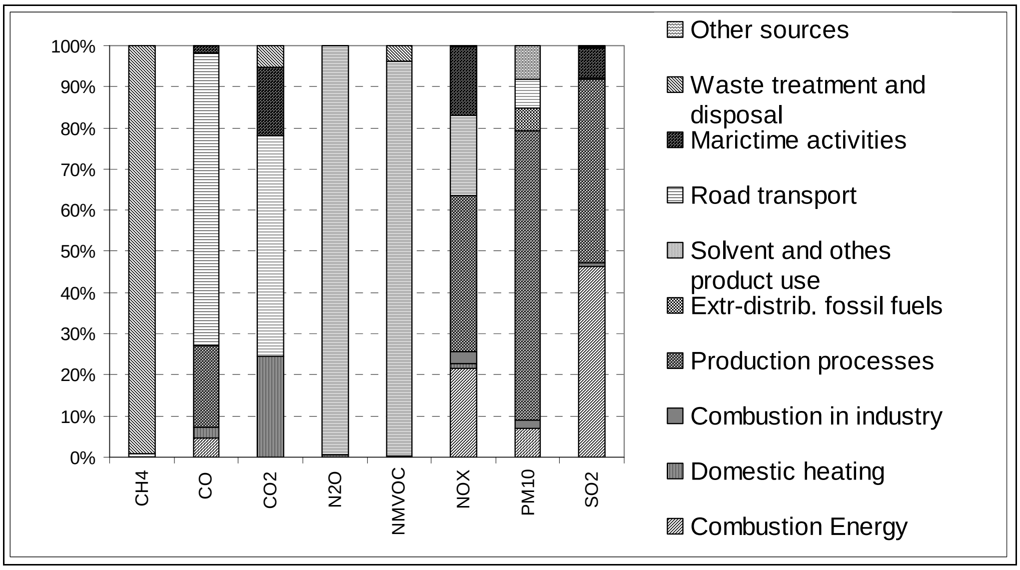


Figure 2. Sources contribution to the total emissions of some considered pollutants.

In figure 2 area and point sources emissions, considered as a whole and referred as SNAP categories, are shown in order to underline the importance of various activities to the total emissions of specific pollutants; in most cases road traffic has the greatest relevance, it represents more than 50% of CO, $CO_2$, $N_2O$ and NMVOC emissions, and less than 20% $NO_X$ ones. For $CH_4$ the largest emissions are due to activities linked to solid waste disposal, while emission data concerning industrial sources are by far the major source of $SO_2$, $NO_x$ and $PM_{10}$.

Road traffic emissions are considered in two ways: as line and area sources. The geography of the road networks, with associated vehicular flows, are available for Taranto city, highways, provincial and state roads. Vehicle emissions estimation is based upon the COPERT III methodology integrated with more detailed emission factors for particulate emissions from brakes and tire wear (IIASA, 2001). The calculation is extended to cover all kinds of driving conditions (highway, rural, urban), taking into account mean speeds and slopes. Traffic emissions for all other populated places are treated as area sources and surrogated from the previous ones, using the number of registered vehicles.

The estimation of emissions from Taranto residential heating is based on yearly fuel consumption, while for all other cities, emissions are surrogated from Taranto ones, using the number of inhabitants. This activity causes about the 25% of the $CO_2$ emissions considered in this study and a little bit less than 1% of $NO_x$ emissions.

Harbour emissions from loading/unloading activities and combustion processes during wharf operations are estimated from mercantile fleet data, average in-port idling time and kind of transported goods. Emissions linked to the quays were derived from detailed information on goods handling. Ship emissions take into account three different stages: maneuvering, hotelling and cruising. Shipping movements in the studied area, vessel data (engine power, fuels,..) (Entec, 2002) were used for emissions estimation. Basing on these data, Lloyd's emission factors (Lloyd, 1999) and elaboration of fuel consumption data at full power (Trozzi et al., 1998), ship emissions in different phases are evaluated.

To feed the dispersion model, yearly emissions are temporally and spatially disaggregated using as possible specific information related to the area. Area emissions from the considered activities are allocated according to the spatial distributions of the related classes of soil usage (residential, industrial, etc.), while time disaggregation is based on the typical patterns of the different activities (production cycles for industries and harbour, vehicle passages, etc.).

**2.4 Models set-up**

A 35x35 $km^2$ model domain was considered to cover all possible impacts on the surrounding areas and all relevant towns. The domain has been horizontally divided into 71 x 71 grid cells with 500 m resolution and vertically splitted from the ground level to the top, set to 1500 m, using layers of variable thickness. Surface parameters were estimated on the basis of the Corine land cover maps. A total of 33 days were selected to simulate air pollution dispersion around the studied area. Fourteen of them were related to the winter season and nineteen to summer one. Their selection was based on both typical local atmospheric circulations/synoptical conditions in the considered season and on the occurrence of pollutants concentration peaks. The 3-D wind and temperature fields generated by the MINERVE meteorological model, the atmospheric turbulence produced by SURFPRO and the emission data were provided as input to the dispersion model. 3D hourly concentrations of $NO_x$, $SO_2$, CO and primary $PM_{10}$ were calculated as total concentration and in terms of contributions of specific sources.

## 3. RESULTS

### 3.1 Comparison with monitoring data

To evaluate model performances the observed $NO_x$, $SO_2$, CO and primary $PM_{10}$ hourly concentrations were compared with the corresponding modeled values. Figure 3 shows a comparison of $NO_x$ observed and modeled concentrations at Orsini monitoring station in winter and summer seasons. The model results exhibits a good reproduction of observed values both in time and concentration value. A few peaks are underestimated but the average values on both seasons are well matched.

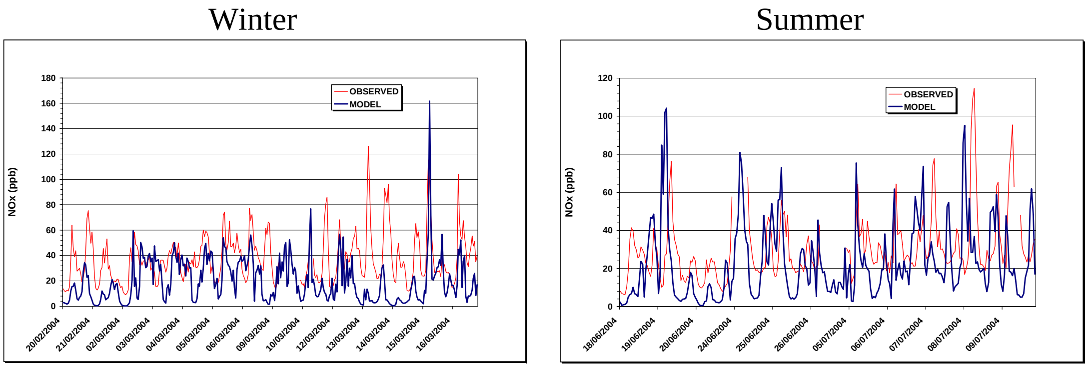


Figure 3. Comparison of observed and modeled $NO_x$ concentrations at Orsini monitoring station.

The $SO_2$ model results in general exhibit peaks higher than observed, with sometimes modeled peaks not revealed by observations. The primary $PM_{10}$ model results indicate an overall underestimation of measured concentrations. This result might be due to possibly missing sources or to an incorrect evaluation of the actual emission factors. A revising of the emission inventory is so required for this pollutant. Background value also needs improvement, but according to the fact that boundary conditions are not used in Lagrangian models, this can only be obtained by enlarging the model domain and including more emission sources. CO model results indicate a general underestimation of the overall average value. The model is able to reproduce the typical morning and evening peaks especially for the urban stations.

### 3.2 Seasonal averaged concentration maps

The 3D hourly concentrations results have been used to calculate daily average maps for each modeled pollutant. To summarize results, overall average winter and summer concentration maps have been calculated starting from daily maps calculated for the corresponding season. Figure 4 shows winter and summer averaged maps of

$NO_x$, $SO_2$, CO and primary $PM_{10}$ concentrations. During wintertime $NO_x$ averaged values up to 50 μg/m$^3$ are foreseen, while at summertime higher peak concentrations (70 μg/m$^3$) are predicted due to a greater mixing of the local atmosphere which drops down pollutants emitted by elevated stacks. The highest winter $NO_x$ peak is located in the urban area of Taranto and a secondary peak is also placed in the Tamburi district close to the industrial area. Other hot spot $NO_x$ peaks can also be observed in the nearby towns. At summertime a large $NO_x$ peak (up to 50 μg/m$^3$) is located around the industrial area, whilst the predicted concentration in the city of Taranto is lower (30μg/m$^3$). Hot spots on the surrounding towns are clearly visible as for winter results. The effect of land/sea breeze on concentrations is also clear visible on summer results. A greater part of the inland territory is influenced by the $NO_x$ concentrations, which extent up to 15 Km from the coastline . The spatial dispersion of $NO_x$ concentrations over the sea is also greater in summer than in winter.
The $SO_2$ winter averaged concentration map shows three peaks with averaged value of 25 μg/m$^3$, located close to industrial area and in the urban area of Taranto. During summertime the averaged concentration map of $SO_2$ shows a maximum located, as for winter results, in the industrial area, with values up to 60 μg/m$^3$, and spreading over the urban area of Taranto with concentrations between 10 and 20 μg/m$^3$. As for $NO_x$ results, the spatial distribution of summer and winter $SO_2$ concentration maps are rather different due to different meteorological conditions.
The winter and summer CO concentration maps both show a traffic related origin, with peaks located in the urban areas and in the connecting roads. Summer concentration values are foreseen to be higher than winter one (200 vs. 100 μg/m$^3$) due to the frequent low wind speed conditions during summer time. The spatial distribution of the predicted concentrations seems not to be affected by the different seasonal meteorological conditions as for $NO_x$ and $SO_2$ results. The concentrations are confined around the emission areas as a consequence of the soil level emission height.
Primary $PM_{10}$ seasonal concentration maps both exhibit an impact area restricted to the industrial district and its surrounding with an extension of 4x4 Km$^2$. The city of Taranto is only partially influenced by this kind of emission. As far as the low accuracy on $PM_{10}$ results is concerned, this estimation needs to be verified. According to the model prediction, the summer concentration are higher (120 μg/m$^3$) than the winter one (70 μg/m$^3$).

### 3.3 Evaluation of source contribution

In order to evaluate the contribution of specific sources to the predicted concentrations, six monitoring stations were selected: three of them are located in the urban area of Taranto (Orsini, Dante and Peripato), two in the city surrounding (Palagiano and Statte) and one in the new urban district of Paolo VI. Results are shown in table 1 for the considered pollutants, in terms of percent source contribution to the total estimated ground concentration (expressed μg/m$^3$) as at each selected monitoring station. Contributions from industry as a whole, traffic, domestic heating, fugitive and harbour activities were considered for contribution analysis.

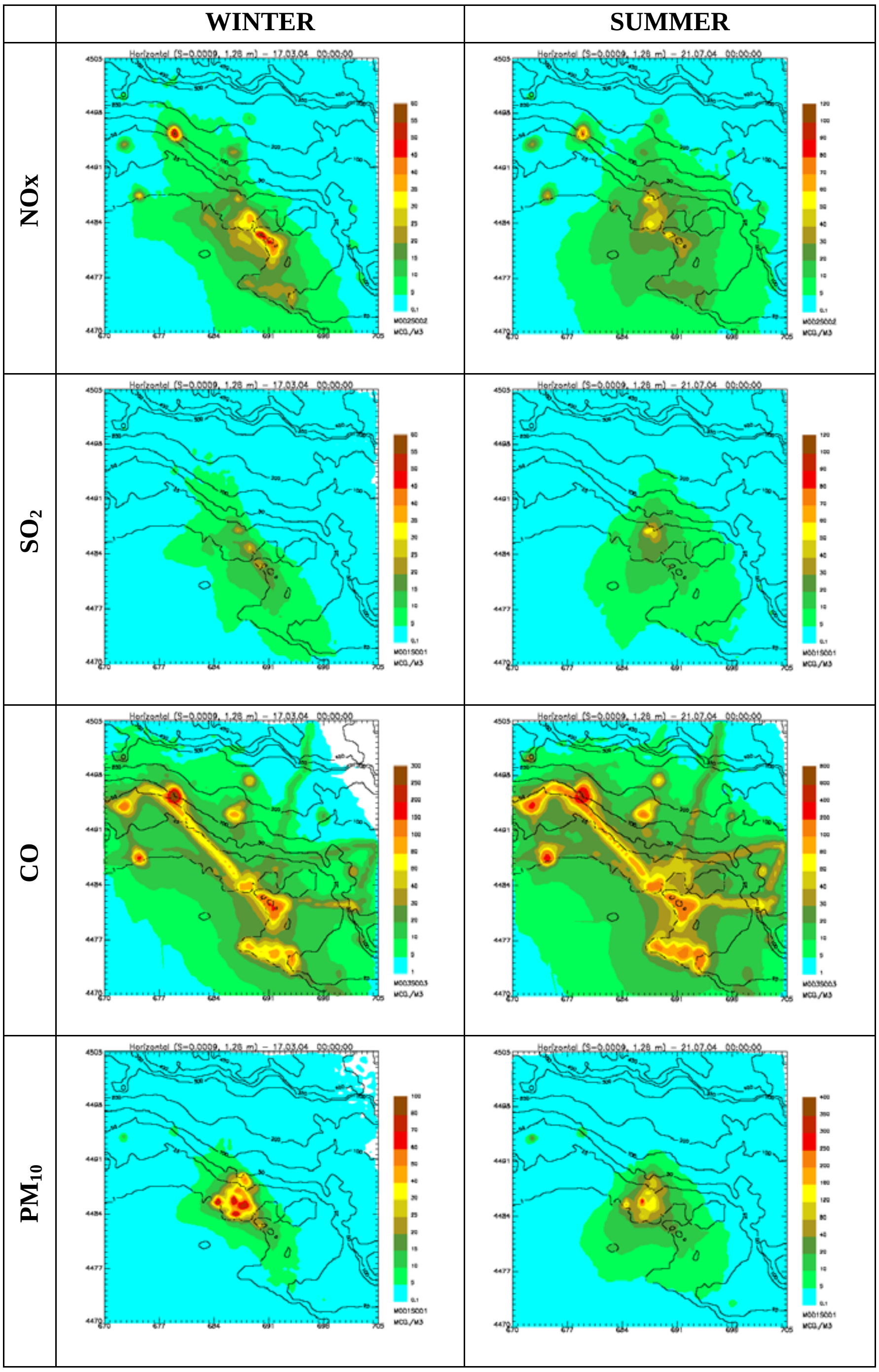


Figure 4. Average concentration maps in winter and summer seasons.

It can be shown industry activities mainly contributes to the total $SO_2$ concentrations (up to 97%) regardless of both station and season. The harbour activities exhibit the second larger contribution with percent values among 3-11%, not considering the result at Palagiano station (23-15%) due to the low total $SO_2$ concentrations (1 $\mu g/m^3$). Low or negligible contributions are instead foreseen for both traffic and domestic heating. The $NO_x$ contributions show some differences among both sources and stations. Industry and traffic emissions are the two main contributors to the estimated total ground concentrations with 41% and 45% respectively on average.

Table 1. Estimation of seasonal pollutants sources contributions at selected monitoring stations (WI (winter); SU (summer)).

| | Dante | | Orsini | | Palagiano | | Paolo VI | | Peripato | | Statte | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **$SO_2$ (%)** | | | | | | | | | | | |
| | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU |
| **Industry** | 92 | 86 | 97 | 89 | 70 | 71 | 91 | 92 | 95 | 89 | 94 | 91 |
| **Traffic** | 2 | 3 | 1 | 1 | 7 | 14 | 2 | 1 | 1 | 2 | 2 | 2 |
| **Domestic heating** | 0 | N.A | 0 | N.A | 0 | N.A | 0 | N.A | 0 | N.A | 0 | N.A |
| **Harbour activities** | 6 | 11 | 3 | 10 | 23 | 15 | 7 | 7 | 4 | 9 | 4 | 7 |
| **Total concen. (μg/m$^3$)** | **15** | **14** | **25** | **26** | **1** | **1** | **2** | **9** | **22** | **19** | **4** | **6** |
| | **NOx (%)** | | | | | | | | | | | |
| | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU |
| **Industry** | 38 | 30 | 65 | 53 | 15 | 16 | 47 | 62 | 64 | 54 | 23 | 22 |
| **Traffic** | 43 | 59 | 24 | 30 | 66 | 74 | 28 | 24 | 24 | 35 | 65 | 73 |
| **Domestic heating** | 13 | N.A | 6 | N.A | 7 | N.A | 15 | N.A | 7 | N.A | 9 | N.A |
| **Harbour activities** | 6 | 11 | 5 | 17 | 12 | 10 | 10 | 14 | 5 | 11 | 3 | 5 |
| **Total concen. (μg/m$^3$)** | **40** | **38** | **36** | **41** | **6** | **3** | **4** | **12** | **44** | **43** | **18** | **21** |
| | **CO (%)** | | | | | | | | | | | |
| | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU |
| **Industry** | 7 | 3 | 7 | 9 | 1 | 1 | 7 | 14 | 12 | 5 | 3 | 2 |
| **Traffic** | 78 | 97 | 80 | 90 | 97 | 99 | 79 | 85 | 77 | 94 | 93 | 98 |
| **Domestic heating** | 15 | N.A | 13 | N.A | 2 | N.A | 14 | N.A | 11 | N.A | 4 | N.A |
| **Harbour activities** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| **Total concen. (μg/m$^3$)** | **131** | **139** | **59** | **76** | **39** | **41** | **15** | **27** | **94** | **108** | **84** | **105** |
| | **$PM_{10}$ (%)** | | | | | | | | | | | |
| | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU | WI | SU |
| **Industry** | 72 | 73 | 62 | 62 | 78 | 65 | 58 | 74 | 82 | 80 | 65 | 69 |
| **Traffic** | 14 | 15 | 2 | 2 | 18 | 33 | 11 | 7 | 6 | 6 | 14 | 18 |
| **Domestic heating** | 4 | N.A | 0 | N.A | 1 | N.A | 2 | N.A | 1 | N.A | 2 | N.A |
| **Harbour activities** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Fugitive** | 10 | 12 | 36 | 36 | 3 | 2 | 29 | 19 | 11 | 14 | 19 | 13 |
| **Total concen. (μg/m$^3$)** | **14** | **18** | **51** | **78** | **3** | **2** | **2** | **7** | **22** | **29** | **3** | **4** |

Both domestic heating and harbour activities contribute for about 9% on average. Results at the selected monitoring stations show some difference among source contributions. The urban stations of Dante, Orsini and Peripato indicate a different impact from industry and traffic. Whilst the Dante station, located downtown, shows a dominant traffic contribution (43-59%), with an industry influence up to 30-38%, the Orsini station, located close to the industrial area, exhibits a prevailing industry impact (53-65%). The same effect can also be observed at the Peripato urban station, located in a urban park close to Mar Piccolo with an open area facing the industry facilities. The urban district of Paolo VI, located north to Mar Piccolo, seems to be mainly affected by industrial sources (47-62%), while traffic contribution at this station can be accounted for 24-28% of the total $NO_x$ concentration. The town of Statte, located north to the industrial area, reveals an industry contribution of up to 23%, whereas traffic is estimated to be main contributor source in this area. The rural area of Palagiano also show a dominant traffic influence (66-74%) but the total estimated $NO_x$ concentration is very low (3-6 $\mu g/m^3$). The harbour NOx contributions exhibit higher values at summertime due to the influence of sea breeze. In particular the Orsini station, closest to the harbour, exhibits the greatest values (17%), followed by Paolo VI (14%). The urban stations of Dante and Peripato both show an harbour contribution at summertime of about 11%. The $NO_x$ summer harbour contribution at Statte is instead about 5%.
CO source contributions are dominated by traffic emission (89% on average) regardless of season and station. The remain contributions can be ascribed to the domestic heating and industries emissions for about the same amount.
Primary $PM_{10}$ concentrations can mainly be attributed to industry emissions (70%). Traffic and fugitive emissions are the two other contributing sources. Among the results obtained in the considered monitoring stations, it is worth to notice the fugitive and traffic contributions at the Orsini station. Here fugitive contributions up to 36% are predicted, being the second largest value, while the traffic one is nearly negligible (2%). This result can be explained with its proximity to the industrial area. The urban stations of Dante show a traffic influence of about 14-15% and fugitive contribution of 10-12%. A lower traffic $PM_{10}$ contribution (6%) is estimated at the Peripato station, in agreement with the lower NOx contributions predicted at the same station for this source. The $PM_{10}$ contribution results at Palagiano, Paolo VI and Statte stations are nearly of the same order of magnitude or lower than other stations, but the total estimated concentrations is significantly low (2-7 $\mu g/m^3$), due to distance from the industrial area, considered as the main emission source for this pollutant.

## 4. CONCLUSIONS

A modeling system based on a Lagrangian Particle dispersion model (SPRAY) has been used to evaluate the impact of the most relevant emission sources located in the city of Taranto and its surrounding areas. Three dimensional $SO_2$, $NO_x$, CO and primary $PM_{10}$ concentration fields have been calculated for the studied area in selected periods covering both winter and summer seasons. The model system has been fed up with both ground and upper air meteorological data and with an on purpose emission inventory taking into account industrial, traffic, domestic heating, fugitive and harbour activities as emission sources. Modeled concentrations have been validated with observed data collected during a proper field campaign.

Results show the impact area of the emitted pollutants extends to a large area of the local territory depending from the pollutant. Typical industrial contaminant, such as $NO_x$ and $SO_2$, locate their concentration peaks around the industrial areas but significant concentrations are found in the surrounding urban and rural areas. The CO concentrations are mainly confined around the emission areas located on urban and motorway roads. Primary $PM_{10}$ peak concentrations are mostly limited in the proximity of industrial areas. A seasonal effect on the ground concentration fields is observed mainly caused by the different meteorological conditions. In particular the summer breeze seems to produce a larger spread of the concentration fields in particular for $SO_2$, $NO_x$ and $PM_{10}$ pollutants.

Source contributions for the modeled pollutants have been calculated at selected monitoring stations. Results indicate a prevailing contribution of industrial activities on the estimated ground concentrations of $SO_2$ and $PM_{10}$. Fugitive particulate emission source is evaluated to be the second larger contributor to the estimated primary $PM_{10}$ concentrations together with traffic. The latter is mainly responsible for the predicted CO concentration. $NO_x$ contribution results point out a more diffuse responsibility, with industry and traffic sources mainly involved with the concentrations of this pollutant, followed by domestic heating and harbour activities with a much lower contribution. The harbour activities have been evaluated to account for mainly $NO_x$ and $SO_2$ ground concentrations, while negligible contributions are foreseen for CO and $PM_{10}$.

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