**H14-152**
# HARBOUR TRAFFIC IN RAVENNA: EMISSION AND DIFFUSION OF PARTICULATE MATTER

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**Abstract:** In this paper we analyse the naval traffic contribution in the particulate PM10concentrations in the port area of Ravenna. Emissions due to ship movement and their diffusion in the port area have been estimated referring to year 2009.The study has been divided into two parts: in the first we calculatedthe annual emissions of particulate matter coming from ship activities (alongside emissions, manoeuvring emissions and emissions from harbour craft), using a standard European methodology; in the second weestimated the diffusion of this pollutants in the whole area.
The dispersion model used, namely ADMS-URBAN, has been applied to estimate areal distribution and concentration levels of particulate matter originating from ships.Manoeuvring emissions are modelled as linear sources; the others as point sources, located at the docks.
Both hourly-concentrations and maximum value of $PM_{10}$ estimatedwith this model has been used to define the source contribution to the particulate matter concentrations at a monitoring station of air quality net placed inside the port area and at one selected receptor.

***Key words: ship** emissions, inventory, model simulation, PM10 concentration*

## 1. INTRODUCTION
The port of Ravenna is the only commercial harbour in Emilia Romagna. Its structure is like a major 'canal' port extending for more than 11 km from the town to the sea (Figure 1). The seaside is protected by two converging dams, each one is 2.800 meters long, while the side towards the city is close to the railway station.

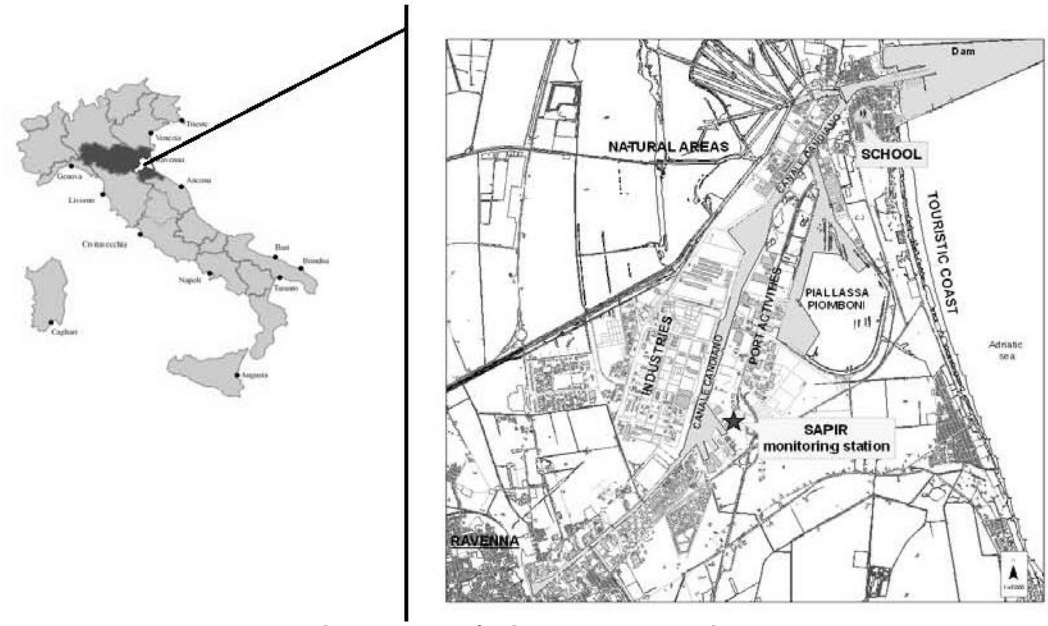



Figure 1:Territorial context, SAPIR fixed monitoring station and source receptor

The port is close to the town of Ravenna (≈ 85 000 inhabitant) and to the tourist littoral, characterized by some residential areas of about 17 000 inhabitant.
In 2009, 18.702 tons of goods were handled and 4743 vessels movements were registered from Harbour Master's office.
This is an area with a high level of air pollution, due to traffic and port-industrial sources, that impacts the surrounding residential areas.
Ravenna is a critical area for high particulate concentrations (along with nitrogen oxides), that exceeds limits and target values required by current legislation. It has been considered meaningful to evaluate the influence to air quality due to maritime traffic, especially for PM10 concentrations.

## 2. EMISSION INVENTORY
Before evaluating maritime transport's impact on the environment, we developed an emission inventory with a bottom-up approach, which is based on port statistics calling referring to year 2009 and supplemented with local ship regulations.
Thanks to these informations, we were able to apply a methodology developed in the framework of the MEET project (Trozzi e Vaccaro, 1998)and updated in 2006 (Trozzi e Vaccaro, 2006) to estimate particulate matter coming from ship emissions.
The MEET methodology estimates emissions of pollutants from 12 ship classes with gross tonnage >100, using appropriate emission factors. It is based on the detailed knowledge of some specific parameters of the ships involved, like engine, time spent in port in the different phases, fuel consumption and gross tonnage. In this way it is possible to calculate ships fuel consumption and consequently, air pollutants emissions for the different ship operation: hotelling, manoeuvring and ship assistance.

The estimate of particulate matter emitted from ships has been obtained by referring to emission factors based on daily fuel consumption for each vessel categories identified. When the fuel consumption value was unknown, it has been calculated as a function of gross tonnage, from linear regression analyses of fuel consumption as against gross tonnage.
The emission rate has been calculated from the following equation (1):

$$E_i = \Sigma_{jklm}\, S_{jkm}(GT)\, .\, t_{jklm}\, .\, F_{ijlm} \qquad (1)$$

where $i$ is the pollutant, $j$ the kind of fuel, $k$ the ship class for use in consumption classification, $l$ the engines type class for use in emission factors characterization, $m$ the operating mode; while $E_i$ is total emissions of pollutant $i$, $E_{ijklm}$ is total emissions of pollutant $i$ from use of fuel $j$ on ship class $k$ with engines type $l$ in mode $m$, $S_{jkm}(GT)$ is daily fuel consumption $j$ in ship class $k$ in mode $m$ as a function of gross tonnage, $t_{jklm}$ are the days in navigation of ships of class $k$ with engines type $l$ using fuel $j$ in mode $m$, $F_{ijlm}$ is the average emission factors of pollutant $i$ from fuel $j$ in engines type $l$ in mode $m$.
Harbour traffic quantification and classification , derived from Harbour Master's office data, are shown in table 1. In the same table we reported the PM10 emission for each ship type in the hotelling and manoeuvring phase. During 2009, PM10 total emissions due to naval traffic has been estimated as equal to 29.5 t/y in Ravenna's harbour.

Table 1. Vessel type, ship count and PM10 emissions (tons) in port of Ravenna during 2009

| Vessel type | Container | General cargo | Liquid bulk | Other | Passengers | Ro/ro | Rail ship | Solid carrier | Tug | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Ship count (number) | 470 | 1233 | 860 | 32,0 | 21 | 158 | 3 | 790 | 1176 | 4743 |
| Hotelling emission (PM10 t/y) | 3,2 | 7,3 | 3,3 | 0,2 | 0,2 | 1,5 | 0,0 | 5,8 | 0,0 | 21,5 |
| Manoeuv. emission (PM10 t/y) | 2,4 | 0,0 | 1,4 | 1,0 | 0,1 | 0,1 | 1,0 | 0,0 | 1,1 | 8,0 |

Figure 2 shows the graduated PM10 yearly emissions from hotelling (Figure 2 a) and manoeuvring (Figure 2 b) for all the harbour's docks .

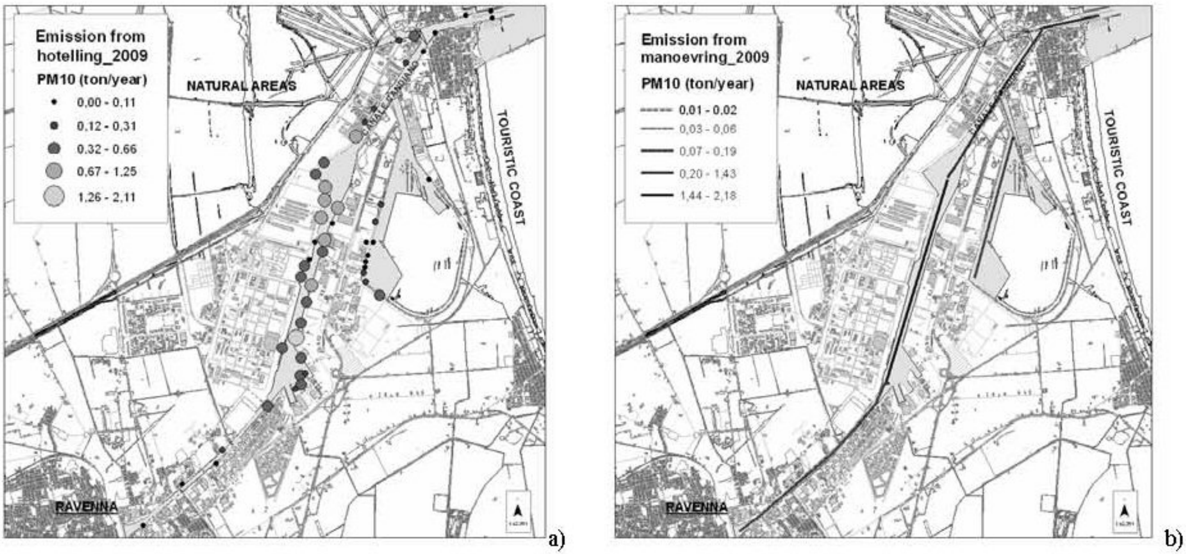



Figure 2: Emission map with graduated symbols for hotelling (a) and manoeuvring (b)

## 3. MODEL SIMULATION

The ADMS-URBAN (version 3.0) used in this study is an advanced Gaussian dispersion model with a normal Gaussian distribution in stable and neutral conditions, in which the vertical dispersion is approximated by two different Gaussian distributions in a convective boundary layer. Furthermore, ADMS applies up-to-date physics using parameterisations of the boundary layer structure based on the Monin–Obukhov length and the boundary layer height. In order to enter the emissions produced by harbour operations, some linear sources have been chosen to represent ship movements along the harbour route (manoeuvring), while point sources were used to represent activity operation at berth (hotelling). For both linear and point sources, we calculated hour by hour temporal variation in shipping emissions.
Meteorological input data (temperature at 10 meters, wind speed and direction at 10 meters, boundary layer height) have been obtained by a nearby meteorological station, for the referring year.
Output concentrations estimated by the model have been calculated according to a long-term simulation, in which the concentrations have been estimated on the nodes of an intelligent grid, formed by 50x50 points, with a 300 meters path, covering the whole harbour area.
Then wecreated a short-term scenario on the individual receptors, which are a fixed monitoring station located in the port area (called SAPIR) and in a school founded southwards to the outer harbour (Figure 1).

**4. RESULTS AND CONCLUSIONS**

In order to evaluate the percentage of PM10 that can be attributed to shipping on annual average, we performed a long term simulation.

Because of non constant emissions, the first model results show no significant influence of ships traffic on annual average PM10 concentration, as evidenced in Figure 3. The dispersion of PM10 concentrations exhibits values which do not excedd 0.12 $\mu g/m^3$ (0,3 % annual mean target value [40 $\mu g/m^3$] but still less than 1% of annual mean particulate concentrations measurable in harbour area).

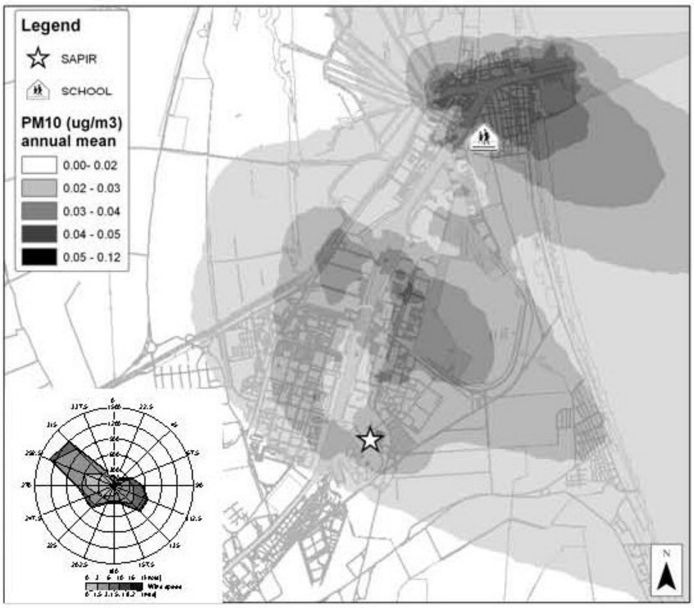



Figure3: Contribution of port emission to the annual average PM10 concentration calculated with ADMS Urban and wind rose for yearly met file

As shown in Figure 3, the pollutants disperse with upper concentrations in two main zones: in the central harbour area, where we can find prevailing emissions due to the hotelling phase; at the port entrance, where the emissions are originated from ships transit and alongside activities.

Major plume spreads to coastline and covers a close residential area, where the school building is located.

PM10 hourly concentrations (short- term simulation) has been calculated in the two individual receptors points (the SAPIR fixed monitoring stations and the school).

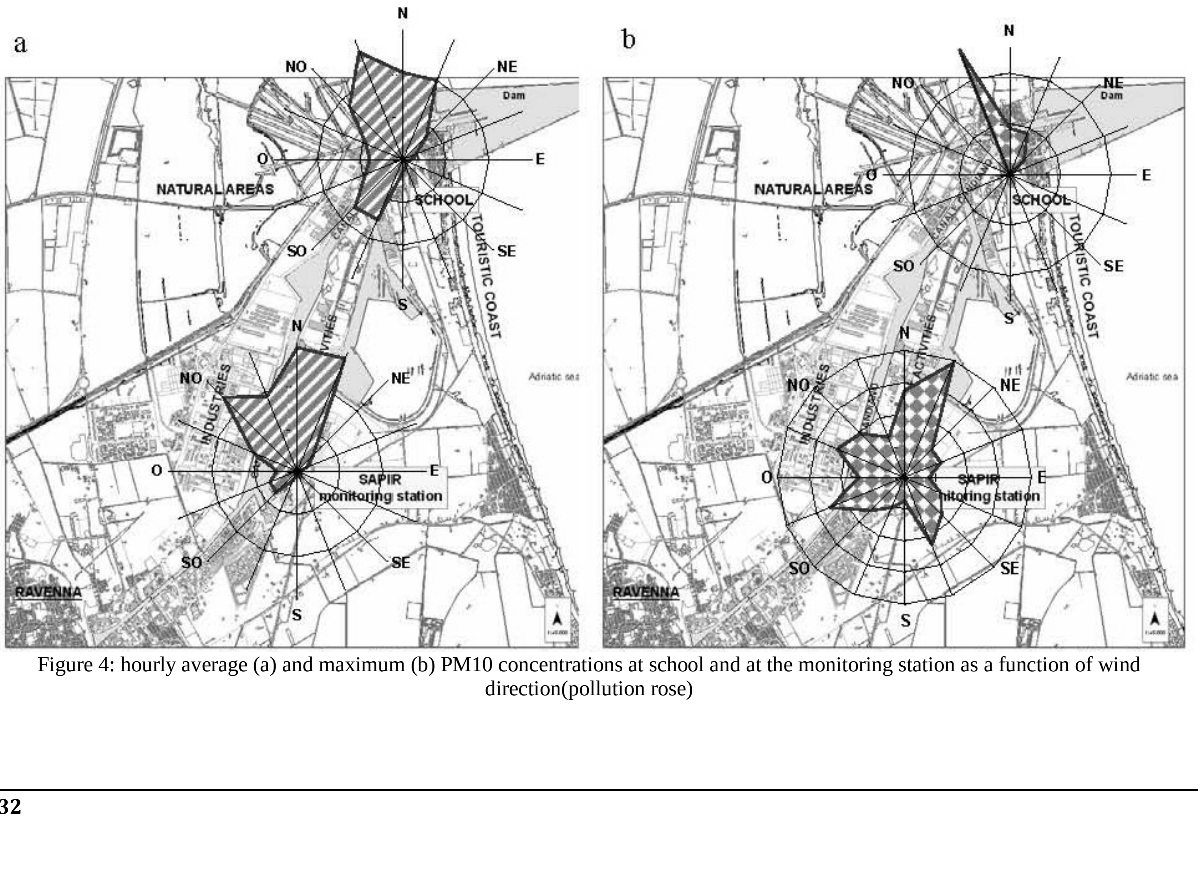



Figure 4: hourly average (a) and maximum (b) PM10 concentrations at school and at the monitoring station as a function of wind direction(pollution rose)

Figure 4 shows some output data processing, concerning hourly average and maximum PM10 concentrations as a function of wind direction (pollution rose) due to naval traffic, respectively at Sapir monitoring station and at the receptor school. The resulting informations are the parts of the harbour where the manoeuvring or/and hotelling provides the greatest contribution at selected receptors.

At Sapir, the major contribution to PM10 concentrations is due to ship traffic in the intermediate section of the Candiano canal and in the Piallassa Piomboni area, where ships are at berth determining maximum values. Instead, the school receptor is most affected by traffic at the harbour entrance: PM10 concentrations are higher,both the minimum and maximum values, when the receptor is located downwind of the port as for this area (N-NW wind direction).

Even if the PM10 annual average is not significant, due to the sensitive receptor as a school critical dayhas been studied in order to evaluate ship traffic contribution to PM10 concentrations when special traffic conditions or weather occur. The worst day for traffic has been selected for both the monitoring stations and the receptor, in order to estimate maritime traffic contribution to PM10 levels.

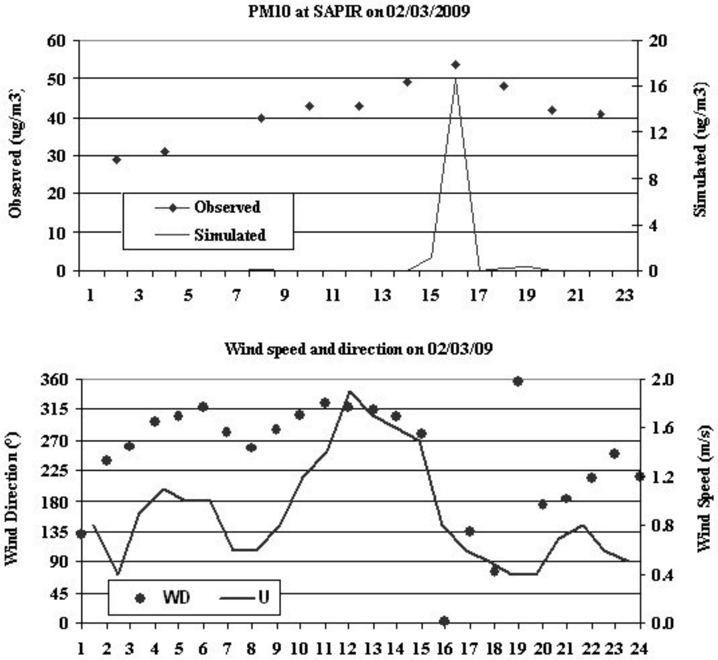
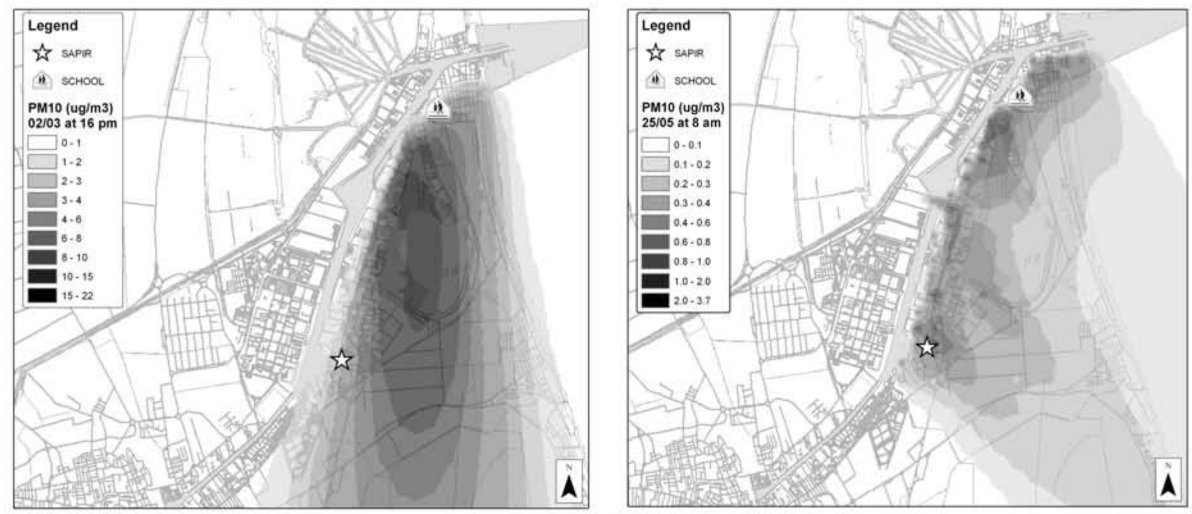



Figure 5:Comparison of observed and modelled PM10 concentrations (a),wind speed and direction (b) on March 2nd2009

First of all, hour-by-hour simulated concentrations have been evaluated in comparison to real data measured in the same day by a SAPIR automatic monitoring site. The model performs the worst on the 2 March 2009, when at 16 p.m. PM10 model concentrations reached the maximum at the monitoring station (17 $\mu g/m^3$). The measured values in SAPIR station, at the same hour and day, reveal a concentration peak of 54 $\mu g/m^3$ (Figure 5a).

As shown in Figure 5b, to 16 pm until 20 pm, the wind speed was lower than 0.8 m/s, with a prevalent north wind direction and the SAPIR monitoring station placed leeward to the flow.




a b

Figure 6: PM10 average concentrations map on March 2nd 2009 at 16 pm (a) and on May 25th at 8 am (b)

In order to attribute the source of this peak, we analysed Harbour Master's office data . On March 2nd , any loading/unloading activities related to highly pulverulent materials were carried out. Additional local meteorogical parameters (see Figure 5b) were not determinant for wind erosion and material handling (since the level of wind speed was low). In the afternoon, from the dock of a private firm, North to SAPIR monitoring station, involved in the offshore structures construction a platform structure movement tow with a tug of more than 10000 t (exceptional transport), that produced consistent emissions,was registered. In Figure 6a we can see a dispersion map showing pollutant concentrations at 16 pm on March 2nd.
Considering a background concentration equal to 23 μg/m$^3$ (estimated in a previous study), the percentage of PM10 measured that can be attributed to shipping activity in the worst case is (Table 2):

PM10 shipping activity % = 100* (PM10 observed conc. - PM10 background conc.) / PM10 simulated conc.

At the same day at school receptor, PM10 estimation results shows the second maximum concentration (3.0μg/m$^3$).

Table2. Estimation of ship activities contribution at monitoring station on March 2nd 2009

| SAPIR station | PM10 simulated conc. (μg/m$^3$) | PM10background conc. (μg/m$^3$) | PM10 observed conc. (μg/m$^3$) | Shipping activity (%) |
|---|---|---|---|---|
| | 17 | 23 | 54 | 45 |

Regarding the first maximum at school receptor (3.7 μg/m$^3$), estimated by model on May 25th at 8.00 am, when port statistics calling registered a high ships traffic, but not so critical. Figure 7 shows speed and wind direction in comparison with PM10 concentration simulated in this point. When the maximum level was reached, wind came from northwest sector with speed lower than 0.8 m/s, or rather blows from the harbour to the school. During this day, concentrations reached the maximum when not favourable meteorogical conditions were determined. In Figure 6b it is represented the dispersion map showing pollutant concentrations at 8 am on May 25th.

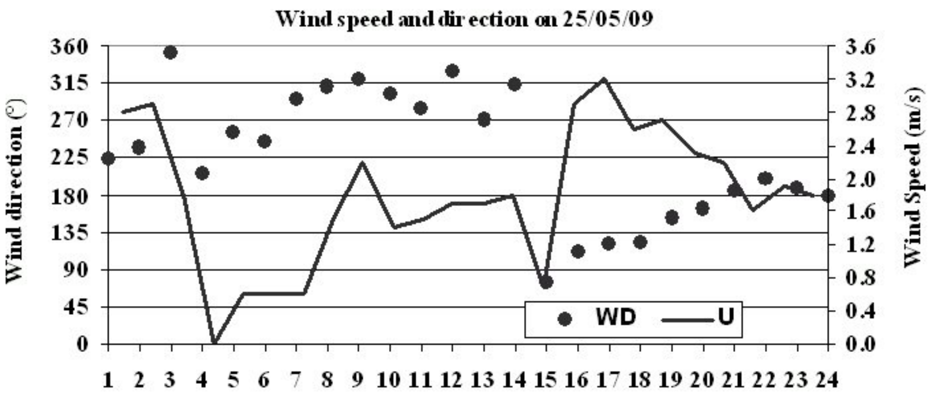



Figure 7: Wind speed and direction and PM10 simulated on 25 May 2009 at school

Table 3 summarizes the emission data recorded during critical days. As reported, on March 2nd 2009, a remarkable level of emissions is originated from hotelling and then from the subsequent manoevring phase, while on May 25th the weather conditions were decisive in the face of normal emission data.

Table 3. Daily ship count and PM10 emissions in port of Ravenna for 02/03/09 and 25/05/09

| | Hotelling emission (PM10 kg/day) | Manoeuv. emission (PM10 kg/day) | Total daily emission (PM10 kg/day) | Ship count at the docks (number/day) | Ship count along the channel (number/day) |
|---|---|---|---|---|---|
| 02/03/2009 | 66.3 | 100.5 | 166.8 | 17 | 30 |
| 25/05/2009 | 51.9 | 34.5 | 86.4 | 15 | 19 |
| Annual average | 53.7 | 40.2 | 93.9 | 13 | 23 |

Therefore the contribution from maritime traffic to PM10 concentrations in harbour area can be considered negligible as annual mean contribution, while it is meaningful to the daily mean PM10 concentrations.

**REFERENCES**

CERC, 2001. ADMS-Urban: Urban Air Quality Management System. User Guide. Version 3.0 CERC Limited, Cambridge.
Trozzi C., Vaccaro R. ,1998, Methodologies for estimating air pollutant emissions from ships. Techne report MEET RF98.
Trozzi C., Vaccaro R., 2006, Methodologies for estimating air pollutant emissions from ships: a 2006 update, Environment & Transport 2th International Scientific Symposium.
UNECE/EMEP, 2002, Group 8: Other mobile sources and machinery, in EMEP/CORINAIR Emission Inventory Guidebook – 3rd Edition October 2002 Update (Technical Report n.30).