CONTRIBUTION OF EMISSIONS SOURCES FROM SHIPPING IN THE PORT AREA OF BRINDISI, ITALY

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Abstract: The present paper is devoted to the evaluation of the contribution of shipping emissions to local concentrations in a relatively large port city (Brindisi) located in southern Italy and characterized by a traffic volume of over 2,000 ships/year. A procedure for building an emission inventory at fine scale is reported along with the modelling study to estimate concentrations in the area. Results for two base years (2010, 2011) show that shipping emissions and associated concentrations were strictly dependent on seasonality and larger contributions were found for NO_X. This confirms, at least for Italian ports, that NO_X are major pollutants from shipping sources which need to be carefully accounted for in the assessment of air quality in coastal/port cities.

Key words: *shipping emissions, MEET methodology, air pollution, ADMS modelling, port city.*

INTRODUCTION

Among the human activities affecting urban air quality, maritime transport is widely considered a major source of air pollution in the world as many large cities are built close to the coast. There are several experimental and numerical studies assessing both pollutant emissions and dispersion from port activities. Shipping emissions can be estimated using various methodologies (EMEP/EEA, 2009). Here we use the one developed by Trozzi, C. and R. Vaccaro (1998) (Methodology for Estimate Emissions from air pollutants Transport - MEET). Previous studies on Italian ports (e.g. Taranto, Ravenna, Venice) showed that the contribution of harbour activities is larger for NO_X and SO_2, while PM_{10} one may be considered negligible (Gariazzo, C. *et al*., 2007; Lucialli, P. *et al*., 2007; Contini, D. *et al*., 2011).

The interest in the evaluation of pollutant concentration from maritime transport is confirmed by the existence of a large number of European projects devoted to this subject. Among those, the ongoing Italy-Greece CESAPO (Contribution of Emission Sources on the Air Quality of the Port-cities in Greece and Italy - www.cesapo.upatras.gr) project originated from the necessity to fill the gaps in the knowledge of the impact of maritime activities on air quality between the two countries in the cities of Patras (Greece) and Brindisi (Italy). The present study is a small part of that project which aims to estimate emissions from ships arriving and leaving the port of Brindisi on one year basis and to evaluate, by means of numerical modelling, concentrations for major pollutants in the area associated to those emissions.

DESCRIPTION OF THE STUDY AREA AND METEOROLOGICAL ANALYSIS

The study area is the port of the Brindisi city located in the southern-east part of Italy. The port, with its over 2,000 ships/year, is one of the most important of the Adriatic sea from tourism, commercial and industrial point of view. Several air quality monitoring stations are located within the port area. Some of them are managed by the Regional Agency for Environmental Protection (ARPA) Puglia and are shown in Figure 1a.

Meteorological data, provided by the Italian Air Force meteorological station located in the Brindisi airport at about 2km far from the study area, were analysed for the years 2010 and 2011. Four months were chosen as representative of the four seasons, namely April (Spring), August (Summer), October (Autumn) and December (Winter). In summertime the most frequent wind direction was from North/North-West, while in wintertime the wind blew mainly from South.

CONSTRUCTION AND ANALYSIS OF EMISSION INVENTORIES

Collection of data and estimation of shipping emissions

The MEET methodology was adopted to estimate air pollutants emissions from maritime traffic. The methodology allows the estimation of emissions from 12 ship classes with gross tonnage larger than 100, using appropriate emission factors for at least two mooring phases in the port: manoeuvring and hotelling. It is based on the knowledge of local maritime traffic volume and some specific parameters of the ships, such as engine type, time spent in port in the different phases, fuel consumption and gross tonnage (Trozzi, C. and R. Vaccaro, 1998). According to the methodology two main steps have been followed, i.e. data collection, analysis and calculation of emissions.

Ship data were available from the Avvisatore Marittimo (http://www.porto.br.it/bpi/index.php) of the Brindisi port. Emission factors for NO_X, SO_2 and PM_{10} were then collected from the European Commission Report (2002) for the manoeuvring and hotelling phases. We then estimated fuel consumption under full power conditions from linear regression analyses of fuel consumption against gross tonnage (Lucialli, P. *et al.*, 2007). A default fraction (0.4 for manoeuvring and 0.2 for hotelling) of maximum fuel consumption was used in order to take into account the real consumption in each phase. By estimating time spent by each ship in the different phases emission rates were finally calculated.

Construction of emission inventories

Since ships positions within the port were unknown, the port was split into four areas (Figure 1b), i.e three containing quays for the hotelling phase (areas 1-3) and one area for the manoeuvring phase (manoeuvring area). Each ship was assigned to the area containing its own quay and to the manoeuvring area. Point sources were chosen for ship chimneys. Two emission inventories typologies were created: the first by considering ship by ship (denoted with SbS), the second by grouping the ships with similar characteristics (denoted with Group). Due to grouping methodology, the latter inventory has slightly different (lower) emission rates than the SbS one and it has been exclusively done to overcome limitations on the number of sources in ADMS modelling. For details on the calculation the reader is reminded to the CESAPO reports (Table 1). Sources were finally randomically positioned in the four areas (Figure 1b). Since data concerning geometric (height and diameter) features and emissive characteristics (exit velocity and temperature) of sources were not available, they were estimated on the basis of literature studies (http://www.slc.ca.gov; http://www.epa.gov; http://www.arb.ca.gov).

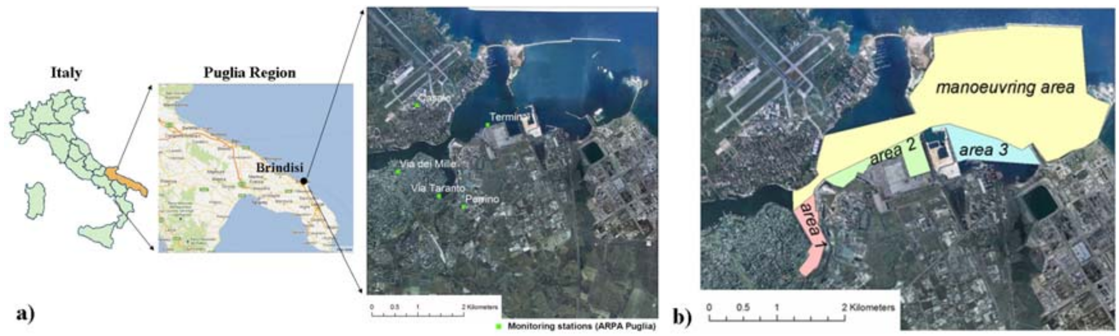

Figure 1. a) Position of the city of Brindisi (middle) in southern Italy (left). The study area and the position of the ARPA monitoring stations (right) close to the port (from Google Earth). b) Subdivision of the port into four areas.

Table 1. Emission rates (gs^{-1}) in the meteorological years 2010 and 2011 for the SbS typology

Emission rate (gs^{-1})	Hotelling			Manoeuvring			Total		
	NO_X	SO_2	PM_{10}	NO_X	SO_2	PM_{10}	NO_X	SO_2	PM_{10}
2010									
August	36.4	35.4	5.3	1.7	1.7	0.3	38.1	37.1	5.6
October	32.8	31.1	4.5	1.3	1.2	0.2	34.1	32.3	4.7
December	35.0	33.4	4.8	1.2	1.2	0.2	36.2	34.6	5.0
Whole year	34.3	32.9	4.9	1.4	1.4	0.2	35.7	34.3	5.1
2011									
April	30.0	28.4	4.1	0.7	0.7	0.1	30.7	29.1	4.2
August	43.4	41.2	5.7	1.2	1.2	0.2	44.6	43.4	5.9
October	37.7	36.0	5.1	0.9	0.9	0.2	38.6	36.9	5.3
December	38.4	37.2	5.3	0.9	0.9	0.2	39.3	38.1	5.5
Whole year	34.7	33.0	4.7	0.9	0.9	0.2	35.6	33.9	4.9

Analysis of shipping emissions

Looking at Figure 1b and Table 1 it can be argued that:

- the total emission rates of NO_X, SO_2 and PM_{10} were similar in 2010 and 2011, with a slight decrease of emission in 2011 mainly due to the manoeuvring phase;
- the hotelling phase contributed to more than 95% to the total emission rates. This is in accordance with the study by Lonati, G. *et al.* (2010) who found a contribution larger than 90% for NO_X, about 80% for SO_X and primary PM;
- seasonality was found to play a major role, as summer emissions were about 10% larger compared to the winter ones. This is in accordance with shipping emissions evaluation of Tzannatos, E. (2010) in the port of Piraeus (Greece) over a twelve-month period;
- finally PM_{10} emission rates were more than 80% lower than NO_X and SO_2, with NO_X being slightly larger than SO_2. These findings are still in accordance with Tzannatos, E. (2010) and Lonati, G. *et al.* (2010) who found NO_X emissions dominant, followed by SO_2 and $PM_{2.5}$.

DISPERSION SIMULATIONS AND SHIPPING CONTRIBUTION TO AIR QUALITY

ADMS modelling set-up

Numerical simulations were performed by means of ADMS-Urban model (CERC, 2011) to estimate concentration levels of NO_X, PM_{10} and SO_2 on a grid of 100 x 100 cells covering an area of 13km x 7km. Five receptors were also located in the position of the ARPA monitoring stations (see Figure 1a). For these simulations no background concentrations were considered since the aim is to estimate solely the contribution of shipping emissions to the air quality in the study area. The percentage of meteorological data used in ADMS simulations was, on average, larger than 80%.

Analysis of results and influence of the emission inventory typology

Table 2 summarizes calculated NO_X mean concentrations. Similar results were found for maximum hourly concentrations and for SO_2 and PM_{10} (not shown here). It can be noted that:

- overall, for both the years and emission inventory typologies, mean concentrations were larger in October even though emission rates were larger in August. This is probably due to larger frequencies of high wind velocity blowing from North-West in August;
- for both the emission inventory typologies, mean concentrations in 2011 were usually slightly larger than in 2010. The concentration increase was more pronounced in December, with a Pearson's correlation coefficient r equal to 0.70, while in August and October it is equal or larger than 0.93;
- for both the years, mean concentrations obtained by using the SbS typology were larger than those obtained by using the Group one due to lower estimated emission rates reported in the previous section. However, we found that the correlation coefficient between concentrations obtained by the two emission typologies (for each month and for each year) is ≥ 0.91. This allowed us to use the Group typology for the whole 2011 simulations without losing much information.

Figure 2 shows yearly mean concentrations (C_{calc}) calculated in 2011. PM_{10} concentrations are lower than SO_2 and NO_X and, for all the pollutants, mean concentrations are larger in the monitoring stations closer or within the port area (Via Taranto, Terminal and Perrino). We expect in those stations a larger mean contribution of shipping emissions.

Table 2. NO_X mean concentrations obtained from ADMS in 2010 and 2011 for the Group (Gr.) and SbS typologies

NO_X ($\mu g m^{-3}$)	2010						2011							
	Aug.		Oct.		Dec.		Apr.		Aug.		Oct.		Dec.	
	Gr.	SbS	Gr.	SbS	Gr.	SbS	Gr.	SbS	Gr.	SbS	Gr.	SbS	Gr.	SbS
Via Taranto	1.5	1.8	3.0	3.6	1.4	2.0	1.7	2.2	1.9	3.6	4.0	5.9	2.5	3.8
Casale	0.5	0.5	1.0	1.1	1.2	1.3	0.7	0.8	0.4	0.8	0.8	1.2	0.4	0.8
Via dei Mille	0.8	0.9	0.8	0.9	0.1	0.1	0.8	0.9	0.5	0.8	1.0	1.3	1.2	1.1
Terminal	2.5	3.6	6.9	6.8	2.9	3.3	5.5	5.6	3.4	3.9	8.4	6.7	15.0	9.8
Perrino	3.9	4.9	2.3	2.6	2.1	2.9	1.9	2.4	3.6	6.2	2.3	3.1	2.1	2.5

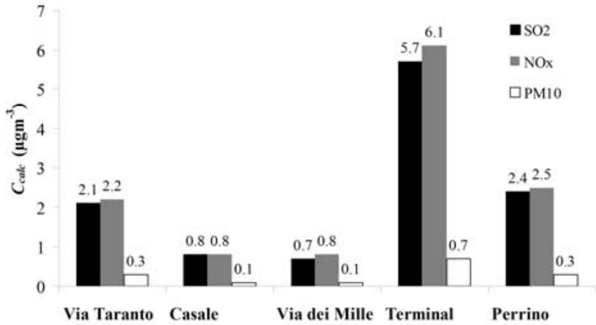

Figure 2. Calculated SO_2, NO_X and PM_{10} yearly mean concentrations (C_{calc}) in 2011 by using the Group typology. Refer to Figure 1a for the position of the monitoring sites.

Shipping contribution to pollution levels

In order to evaluate the contribution of shipping emissions to measured concentrations, Table 3 shows the percentage differences for some months calculated as $\% = 100 \times C_{calc} / C_{meas}$, where C_{meas} is the measured value.

- NO_X average contributions were in the range 5-12%, in accordance with findings of Lucialli, P. *et al.* (2007) in Ravenna As expected from results discussed above, larger contributions were found in the monitoring stations closer or within the port area, showing peaks up to 30%. Seasonality was found to play a major role on the average contributions (see also Figure 3), which were 5-10% in winter and 7-12% in summer. This is in accordance with Gariazzo, C. *et al.* (2007) who found an average contribution of 9%, with 3-10% in winter and 5-17% in summer in the Taranto port;
- SO_2 contributions are not shown since they were found to be larger than 100% probably due to overestimated emission factors considered in the last officially released European Commission Report (2002), which does not take into account the progressive decrease of the sulphur oxides in the fuel from 1.5% (before 2010) to 1% in the Emission Control Area (SECA) (Annex VI - Marpol 73/78; European Directive 2005/33/CE). Further, no chemical reactions were considered;
- PM_{10} average contributions were below 3%, in accordance with the experimental study of Contini, D. *et al.* (2011) in the Venice port, who found the contribution of $PM_{2.5}$ and PM_{10} to be 1 to 8%.

Table 3. Percentage contribution of shipping emissions (by using the SbS typology) to monitored mean concentration levels NO_X and PM_{10} for some months in 2010 and 2011. *Values for the whole year 2011 refer to Group typology

NO_X (%)	**Oct. 2010**	**Dec. 2010**	**Apr. 2011**	**Aug. 2011**	**Whole 2011***
Via Taranto	10	5	7	14	6
Casale	6	6	6	4	5
Via dei Mille	2	< 1	3	3	2
Terminal	17	8	16	10	17
Perrino	N/A	N/A	12	29	11
Average	*9*	*5*	*9*	*12*	*8*
PM_{10} (%)					
Via Taranto	3	1	1	2	1
Casale	1	1	1	< 1	1
Via dei Mille	1	< 1	< 1	< 1	< 1
Terminal	5	2	3	2	3
Perrino	N/A	N/A	1	3	1
Average	*3*	*1*	*1*	*2*	*1*

Finally Figure 3 shows that, overall, high pollution spots (due to shipping emissions) are located in the hotelling area. It would thus be informative to locate a monitoring station in the South-East zone.

CONCLUSIONS

An air pollution assessment study was conducted for NO_X , SO_2 and PM_{10} shipping emissions in the port of Brindisi characterized by a traffic volume of over 2,000 ships/year. Results for two base years (2010,

2011) have shown that the seasonality plays a major role in the contribution of both shipping emissions and associated concentrations on the air quality. It is found that, at least for Italian ports, NO_X from shipping sources need to be carefully accounted for in the assessment of air quality in coastal/port cities.

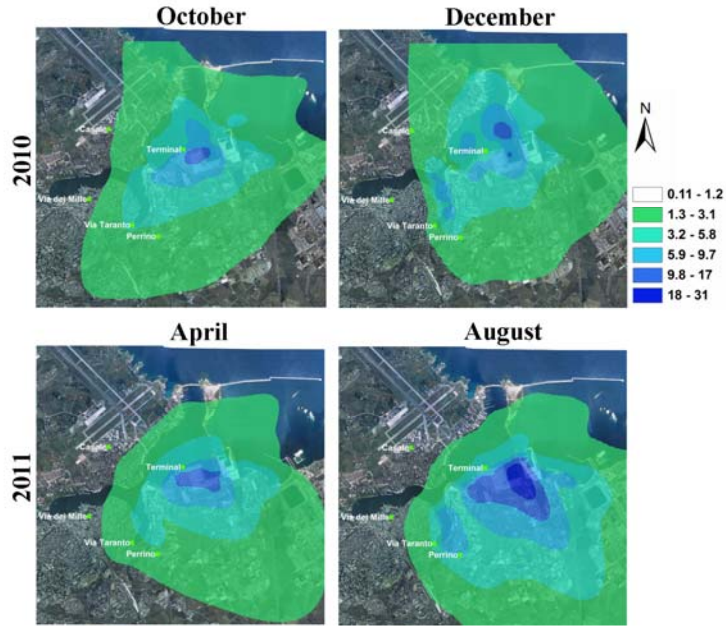

Figure 3. NO_X mean concentration (μgm^{-3}) contours at 4m height in October and December 2010 (top), April and August 2011 (bottom) for the SbS inventory typology.

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REFERENCES
CERC, 2011: ADMS Urban USER Guide. Available from Cambridge Environmental Research Consultant, Cambridge, UK. http://www.cerc.co.uk/

Contini, D., A. Gambaro, F. Belosi, S. De Pieri, W. R. L. Cairns, A. Donateo, E. Zanotto and M. Citron, 2011: The direct influence of ship traffic on atmospheric $PM_{2.5}$, PM_{10} and PAH in Venice. *Journal of Environmental Management*, **65**, 2119-2129.

EMEP/EEA, 2009: Air pollutant emission inventory guidebook, published by EEA (European Environment Agency), Technical report No 9/2009.

European Commission Report, 2002: Quantification of emissions from ships associated with ship movements between ports in the European Community. Final Report.

Gariazzo, C., V. Papaleo, A. Pelliccioni, G. Calori, P. Radice and G. Tinarelli, 2007: Application of a Lagrangian particle model to assess the impact of harbour, industrial and urban activities on air quality in the Taranto area, Italy. *Atmospheric Environment*, **41**, 6432–6444.

Lonati, G., S. Cernuschi and S. Sidi, 2010: Air quality impact assessment of at-berth ship emissions: case-study for the project of a new freight port. *Science of the Total Environment*, **409**, 192-200.

Lucialli, P., P. Ugolini and E. Pollini, 2007: Harbour of Ravenna: The contribution of harbour traffic to air quality. *Atmospheric Environment*, **41**, 6421-6431.

Trozzi, C. and R. Vaccaro, 1998: TECHNE report MEET RF98, Methodologies for estimating air pollutant emissions from ships, August 1998.

Tzannatos, E., 2010: Ship emissions and their externalities for the port of Piraeus – Greece. *Atmospheric Environment*, **44**, 400-407.