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Contribution of in-port shipping emissions to gaseous pollutants and particulate matter of different sizes in an Adriatic port-city

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Abstract

In recent years, shipping emissions are a growing concern because of their impacts on air quality and climate in coastal areas. In particular, in-port ship emissions are harmful for local communities since the proximity of the main harbours to urban agglomerates. Few studies are focused on size distribution and number concentration of emitted particles, especially at low loads (e.g., manoeuvring and hotelling). In this work, the contributions of maritime emissions to gaseous pollutants and particles of different sizes (range 0.009-32 μm) distinguishing manoeuvring and hotelling phase (including loading/unloading activities) are reported. Results show that the estimated contributions of the two phases are different in terms of size distributions of the emitted particles and could be efficiently described using four size intervals. Hotelling has greater impact on particles with diameter D_p<0.25 and D_p>1 in number concentration while manoeuvring phase contributes substantially on mass concentration of particles between 0.4 and 2.5 μm. Finally, harbour logistic plays a significant role in determining the total impact of shipping of the nearby coastal areas, especially in terms of PNC (particle number concentration) that need further studies.

Keywords: Shipping impacts; Particle number concentration; Size distributions

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1. Introduction

Maritime transport is a growing concern for its implications on air quality of coastal areas and on climate. It is difficult to quantify global emissions of shipping, mainly CO_2, NO_X, SO_2, and particulate matter (PM), therefore, shipping is one of the least regulated anthropogenic source of atmospheric pollution (IMO, 2008).Many regulation efforts, made at international level, rely on the reduction of sulphur content in ship fuels when used in harbour and in the Emissions Control Areas (ECAs) (Directive 2005/33/EC) and on the deployment of alternative fuels infrastructures (Directive 2014/94/EU).These strategies could lead to a local benefit being able to reduce the shipping contributions to $PM_{2.5}$ (Contini et al., 2015) and to SO_2 concentrations (Schembari et al., 2012); however, they have limited effects on PAHs and metals (Gregoris et al., 2015).

Shipping typically contributes with 1-7% to the annual mean PM_{10} levels, with 1-20% to $PM_{2.5}$, and with 8-11% to PM_1, especially in coastal areas (Viana et al., 2014). Emissions within harbours are a relatively small fraction of global shipping emissions but they can have important effects on human health (Viana et al., 2015) and climate in coastal areas and in nearby urban agglomerates.

In-port shipping emissions are substantially dependent on operational phase (manoeuvring and hotelling)because of the differences in auxiliary and main engines, and because of the use of low-sulphur content fuel (0.1% mandatory during hotelling in European harbours). Since ships at berth spend usually one or more days while manoeuvring phase lasts only a few hours (Su Song, 2013), there is an interest to study emissions from different fuels in port areas and their effects on human health and ecosystems. Anderson et al. (2015) demonstrates that the use of HFO (Heavy Fuel Oil) produces more particles (both in number and mass), shifting the associated size distribution modes to larger diameters. There are limited studies on size distributions up to coarse particles, of ship emissions (Lyyaren et al., 1999; Moldanovà et al., 2009; Merico et al., 2016) because most of the analysis are focused on fine particles (Kasper et al., 2007; Petzold et al., 2008; Pirjola et al., 2009;Jonsson et al., 2011; Dietsch et al., 2013;Kivekäs et al., 2014).

In this work an analysis of the contribution of shipping to gaseous and particulate pollutants is performed discussing the relative weight of hotelling and manoeuvring phases.

2. Site description an instrumental setup

The measurement site is located inside the harbour area of Brindisi, a South-Eastern Italian port-city (88,500 inhabitants) with a complicated scheme of anthropogenic source emissions (Fig. 1) including an international airport (3 km NNE), a large industrial area, three thermo-electric power plants, a harbour (E of the urban agglomerate).

The port area is ideally divided into three basins dedicated to host different typology of ships. The internal zone (about 700,000 m^2 with 2 km of docks) is essentially the main accommodation for tourist activities with a capability up to 8 Ro-Ro moored at the same time. The central zone (1,200,000 km^2 with 3 km of docks) hosts commercial ships. From the available docks fuels are transported to the two thermoelectric plants located to the South and North of Brindisi. The outer harbour (3,000,000 m^2) has industrial piers for coal ships, bulk carriers and small general cargo. Raw materials are handled for supplying the near industrial chemical pole. Its yearly traffic is over 9.5 Mtons of goods, 520,000 passengers and 175,000 vehicles (Source: Avvisatore Marittimo Brindisi, 2010-2011).

A dedicated field campaign was carried using a Mobile Laboratory located near the Passenger Terminal (40°38′43.32″ N–17°57′36.39″ E), facing (about 50 m) the water and ferryboat docks. Measurements were taken in summertime, from 27/06/2014 to 13/10/2014, when the volume of ship traffic was at maximum.

Fig. 1. Details of the Brindisi area and location of the measurement site

Different instruments operating at high and low temporal resolution were installed. A micrometeorological station, composed by a three-dimensional ultrasonic anemometer (R3, Gill Instruments) and a slow response thermo-hygrometer (Rotronic MP100A, Campbell Scientific) was used. Particles were measured using a Condensation Particle Counter (CPC, Grimm Aerosol Model 5.403, 1 Hz, size range 0.009–1 μm), for total Particle Number Concentration (PNC), an Optical Particle Counter (OPC, Grimm 1.109, 31 channels, 1-min resolution, size range 0.25-32 μm) for PNSD (Particle Number Size Distribution) and PMSD (Particle Mass Size Distribution). Gaseous concentrations of O_3, NO, NO_2, NO_x and SO_2 were measured with a temporal resolution of 5 minutes using a Teledyne-API (400E O_3 analyser), a Teledyne-API (200E NO, NO_2, and NO_X analyser), a Teledyne-API (M100E SO_2 analyser). A videocamera collected photos (every 30s) to monitor departure/arrival of ships and vehicles passing in the area facing the dock and to synchronize the dataset of ship traffic with concentrations measurements.

3. Methodology

The approach developed in Contini et al. (2011), firstly applied in the Venice area and then extended in Brindisi harbour (Donateo et al., 2014), was used to quantify the primary contribution of ship traffic to the different pollutants. The measurement site was considered directly influenced by shipping emissions when at least a ship was berthed and the measurement site was downwind. Three wind direction sectors associated to the docks were identified: 292.5°-0°, 270°-345°, and 10°-45° for analysis of the hotelling periods. The statistical analysis was based on integration of data concentrations (30-min averages), wind directions and ship traffic (arrival/departure) synchronized with the concentration measurements. The contribution was computed following Eq. 1, where C_{DP} was the average concentration in the selected wind direction sectors and in periods potentially influenced by ships; C_{DSP} was the average concentration not significantly influenced by ships; C_D was the average concentration in the wind direction sectors; F_P was the fraction of cases influenced by ships.

$$\varepsilon_C = \frac{(C_{DP} - C_{DSP})F_P}{C_D} = \frac{\Delta_P F_P}{C_D} \quad (1)$$

The contributions were estimated in two cases: only manoeuvring and hotelling plus manoeuvring. Vehicular traffic (car and trucks passing in the area facing the dock) associated to loading/unloading activities was included in the total impact evaluation. In this case, an appropriate threshold of 10 vehicles in each 30-min period was assumed. The uncertainties of the estimations were calculated considering the variability obtained changing the wind direction sectors definitions of ±10°.

4. Results and discussion

The contribution of shipping is investigated distinguishing manoeuvring (arrival and departure of ships) and hotelling phases (including loading/unloading activities). The latter represents over 90% of the estimated shipping emissions, except for SO_2 (Merico et al., 2016).

The plumes released are visible on high resolution measurements of gaseous and particle concentrations with a typical plume-like behaviour, modulated by operational activity and meteorological conditions (Fig. 2).SO_2 concentration presents brief peaks at arrival/departure of ships; however, hotelling does not influence significantly concentrations due to the use of low-sulphur content fuel in harbour. Peaks of nitrogen oxides (NO and NO_2) are present in all period, both during manoeuvring and hotelling. Also, in correspondence of NO peaks a depletion of O_3 is observed in both phases. This is a local effect, as demonstrated by large numerical modelling results on the Mediterranean Sea (Aksoyogluet al., 2015), and specifically in the Adriatic Sea (Gencarelli et al., 2014).

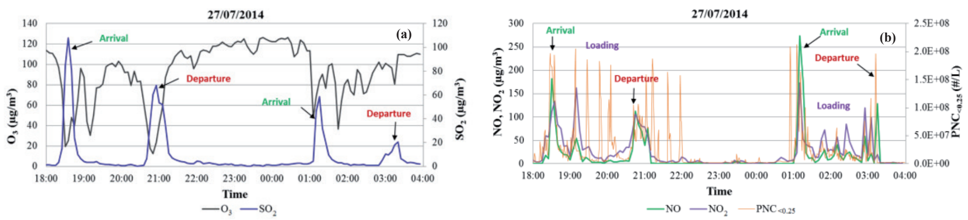

Fig. 2. Example of high resolution measurements with concentration peaks related to the different phases for (a) O_3, SO_2 and (b) NO, NO_2 and $PNC_{<0.25}$

The average primary contribution to the different atmospheric pollutants (Fig. 3a) highlights that hotelling phase adds more than half of the total contribution to NO, NO_2 and PNC. The related titration of O_3 during hotelling is 56% of the total reduction (about 5%).The analysis of the contributions to particles of different sizes (Fig. 3b) allowed to put in evidence four size intervals. Plumes released when ships are moored, together with related loading/unloading activities, influence substantially $PNC_{<0.25}$ (53%) and $PNC_{>1}$ (61%). Accumulation mode particles ($PNC_{0.4-0.25}$) are mainly linked to manoeuvring phase, because of the hotelling weight reduced to 23% of the total contribution in this range and no influence on $PNC_{1.0-0.4}$ (Fig. 3b).

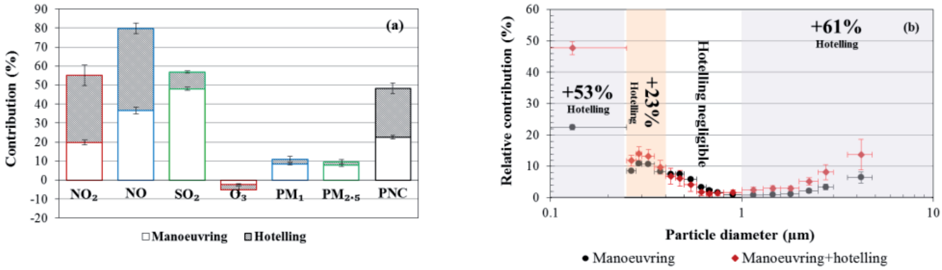

Fig. 3. (a) Relative contributions to gaseous pollutants, PM_1, $PM_{2.5}$ and PNC; (b) relative contribution to PNC as function of particle diameter with indication of percentage of hotelling weight to the total estimation

In conclusion, it is clear that harbour logistics plays a crucial role in determining the total impact of shipping in coastal areas. In particular, since during hotelling PNC increases, it should be considered the importance of particle emissions even in port areas when reduced loads are used (Anderson et al., 2015). Also, the reduction of sulphur in ship fuels could decrease the emissions of nanoparticles.

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