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Impact on air quality of cruise ship emissions in Naples, Italy

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GRAPHICAL ABSTRACT

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ABSTRACT

The Municipality of Naples, with about 1 million residents and about 3 million people living in the surroundings, suffers, as for many a city, from low air quality, as demonstrated by the concentration level of pollutants measured by fixed monitoring stations of the Regional Air Quality Network. The port of Naples is among the most important ports in the Mediterranean sea with a large traffic of passengers and goods. Therefore, it contributes to atmospheric pollution of the nearby urban area with ship emissions. Public authorities need to know the contribution of different sources of atmospheric pollutants to put effective environmental policies into practice. In this article, a bottom-up methodology has been developed to assess the amount of atmospheric pollutants emitted by cruise ships traffic and its impact on the atmospheric pollution in Naples. A detailed description of in-port activities of cruise ships has been applied to calculate emission rates of NO_x and SO_x by using standard procedures corrected and integrated by real data to better evaluate actual engine power applied and fuel consumption. Considered activities include: navigation in port both at arrival and departure; maneuvering for berthing and unmooring and hoteling at berth. The study covers all cruise ship calls during the year 2016. The impact of cruise ship emissions on the urban area has been assessed by using the Gaussian puff model CALPUFF, thus obtaining contour maps of 1-h and year average values. Finally, in order to assess the contribution of cruise ship emissions to air quality, simulations have been compared with concentrations measured at fixed monitoring stations and during a monitoring campaign.

1. Introduction

Shipping represents a growing asset within the transport sector. The latest UNCTAD (United Nations Conference on Trade and Development) review of marine transport confirms that more than 80% of global trade is transported annually by sea (UNCTAD, 2013). Mirroring the world economy, the demand for transport services in 2016 has improved moderately. The UNCTAD's projections for the medium term estimates an average growth rate of 3.2% over the period from 2017 to 2022. In Italy, 37% of the commercial exchange in the first nine months of 2016 has travelled by sea.

Cruise tourism has experienced rapid growth in recent years. Globally, from 2003 to 2013, the worldwide demand for cruising has increased from 12.0 to 21.3 million passengers (+77%); and from 2013

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to 2015 to 23.9 million passengers (+12%) (CLIA, 2014; CLIA, 2016). In 2013, ports in the Mediterranean and the Baltic sea were the most visited in Europe, thus generating an increase of visitors of 8.7% compared to 2012, out of a total of 250 port cities. In fact, the Mediterranean is the second largest cruise market in the world and represents 21.7% of the annual cruising capacity in 2013 (CLIA, 2014; MedCruise, 2014).

With the simultaneous decrease of terrestrial emission sources, following the Kyoto Protocol, for some pollutants, there was an increase in the relative weight of the maritime emissions on the total anthropogenic emissions (Viana et al., 2014). As a matter of fact, emissions from ships are included in the list of pressures that should be reduced or minimized in order to maintain or obtain a good ecological status in the Marine Strategy Framework Directive 2008/56/EC of the European Parliament (Blasco et al., 2014).

The regulation of pollutants from maritime traffic is the subject of MARPOL (MARine POLlutants) 73/78 Annex VI, legislation issued by the IMO (International Maritime Organization). According the current legislation, ships trading in the special areas, the so-called SECA (SOx Emission Control Areas), have been allowed to use fuel with maximum 0.1% since January 1st, 2015. Out of the SECA areas, the maximum sulphur limit has been reduced from 4.5% to 3.5% since January 1st, 2012 and finally it will come to 0.5% starting from January 1st, 2020. Nowadays the EU Directive 2005/33/EC imposes the use of fuels with sulphur content of less than 0.1% by weight to all ships at berth in harbours. There are also effective national regulations or initiatives that aim at reducing SO_2 emissions from ships, such as voluntary agreements at local scale in the Mediterranean Sea (Contini et al., 2015) and in harbours along the California coastline (Tao et al., 2013).

The impact of ship emissions is of global and local scale. The first concerns mainly emissions during the navigation phase. The contribution of maritime traffic to global emissions is estimated in 5.6 Tg of NO_X (as N) and 5.3 Tg of SO_X (as S) (Smith et al., 2014). In any case, there has been a reduction in terms of global GHG emissions from 2.8% in 2007 to 2.2% in 2012 (Smith et al., 2014).

Although local emissions are a small fraction of global transport emissions (Entec, 2002), they can have serious effects on human health, especially in coastal areas and port cities. About 70% of the ship emissions occurs within 400 km from the coast, and it contributes typically with 1–7% to the annual mean PM10 levels, with 1–20% to PM2.5, and with 8–11% to PM1 in coastal areas (Viana et al., 2014).

Therefore, numerous studies have been published with the aim of evaluating the emissions of ships in ports (Saxe and Larsen, 2004; Battistelli et al., 2012; Saraçoglu et al., 2013; Fan et al., 2016; Merico et al., 2017; Chen et al., 2017, 2018). Generally, there are two different approaches to estimating emission inventories: bottom-up and top-down. The bottom-up approach is much more accurate, but significant efforts need to be made for data collection and analysis, particularly for large-scale studies (Miola et al., 2009; Miola and Ciuffo, 2011; Berechman and Tseng, 2012; Smith et al., 2014; Tichavska and Tovar, 2015).

A complete bottom-up procedure includes the following steps: i) inventory of ships arriving and staying in port in the period of interest; ii) determination of the characteristics of ships; iii) determination/prediction of power released from engines on-board; iv) prediction of pollutants emission in port; v) determination of the impact on the environment by using a model to simulate the dispersion of pollutants in the atmosphere.

The first two steps are generally not problematic. Calendar of arrivals and departures are generally public. Data of ships (GT, Main Engine nominal power, length and so on) can be found in various specialistic databases.

Generally, for a ship in a port, two different phases are identified: maneuvering and mooring. The maneuvering mode, including slow cruising in port area, approaching/docking and departing, begins with the deceleration of the ship and ends at landing, restarting from the mooring and then ending when the speed is reached just outside the port's borders. Precise procedures consider separately the activities included in the maneuvering mode separately and evaluate the corresponding emission rates. The mooring phase corresponds to the time a cruise ship stays in port and provides hotel services on board to passengers and crew members. During this time the main engine (ME) is turned off and all power requirements are covered by auxiliary engines (AE) or, if the ship has a diesel-electric system, as usual for cruise ships, the ME works at limited load factor producing the energy required.

A comparative analysis of current methods for estimating energy consumptions and shipping emissions during navigation mode is reported by Moreno Gutierrez et al. (2015). Papaefthimiou et al. (2016) report the results of a bottom-up methodology based on in-port ships activity to calculate exhaust pollutant emission rates (NOx, SO2, and PM2.5) during moving, maneuvering and hoteling for international cruise ship journeys to and from 18 ports of Greece during 2013. De Melo Rodriguez et al. (2017) provide a regression analysis between emission indicators (CO2, NOX, SOX and PM) and independent variables (port time, passenger capacity and vessel GT). The analyses were performed (with surveys and interviews of cruise shipping companies) on 30 cruise vessels in the port of Barcelona by evaluating the load factor and working time of the thrusters, type of fuel used (HFO or MGO/MDO) and hoteling electric power (kW) used during berthing activity. The most appropriate indicators are: inventory emissions per port-time gross tonnage, port-time passenger and port time. These results can be applied to other ports as well.

In order to assess the impact of ship emissions on nearby urban areas, two different kinds of approach exist: experimental observations and numerical modelling of atmospheric dispersion. Some authors carried out monitoring campaigns on selected pollutants and applied data analysis techniques (e.g. source apportionment) to evaluate the contribution of each source (Pérez and Pey, 2011, Cesari et al., 2014). Particulate matter and heavy metals are generally adopted as tracer pollutants. A factor/source characterized by V and Ni is a typical factor associated with heavy oil combustion, including shipping (Viana et al., 2014; Bove et al., 2014). Among gaseous pollutants SO_2 is often indicated as tracer of ship emissions (Prati et al., 2015). However, the collection of monitoring observation followed by data analysis is a quite long and expensive procedure and does not always produce clear indications, due to the presence of other sources of pollutants such as: urban traffic, domestic and commercial heating, industry. Therefore, the use of dispersion models is more frequent. Many different dispersion models have been adopted (Saxe and Larsen, 2004; Merico et al., 2017; Chen et al., 2017, 2018; Fan et al., 2016; Saraçoglu et al., 2013). Gariazzo et al. (2007) used a Lagrangian particle model to assess the impact of harbour, industrial and urban activities on air quality in the Taranto area (Italy). Merico et al. (2017) have studied air quality shipping impact in the Adriatic/Ionian area focusing on four port-cities: Brindisi and Venice (Italy), Patras (Greece), and Rijeka (Croatia) and using a WRF-CAMx modelling system. Poplawski et al. (2010) have used CALPUFF model to investigate the impact of cruise ship emissions on level concentrations of fine particulate matter (PM2.5), Nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2) in James Bay, Victoria, British Columbia (BC), Canada. The same model CALPUFF was used in order to assess the impact on local air quality due to atmospheric emissions of a new port in project in the Mediterranean Sea (Lonati et al., 2010).

A study of the impact of merchant ships with large size two-stroke diesel engines emission in the port of Naples is reported by Iodice et al. (2017). The aim is the development of a methodology to assess the impact of pollutant emissions from marine engines in manoeuvring mode and in fuel switch conditions from heavy sulphur residual fuel oil to low-sulphur distillate fuel oil. The authors use a steady state Gaussian model in long time version with a certain degree of approximation, as reported by the same authors. Their conclusion is that in the port of Naples NO2 and SO2 concentration levels may be affected by merchant ship emissions, albeit without a crucial percentage contribution. This