HARMO22
22nd International Conference on
Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
10-14 June 2024, Pärnu, Estonia

# HIGH-RESOLUTION MODELLING AND OBSERVATIONS OF PRESENT AND FORESEEN SCENARIOS IN THE CITY-PORT OF CIVITAVECCHIA (ITALY)

*G.L. Tinarelli[1], S. Trini Castelli[2], F. Barnaba[3], G.Gobbi[3], C. Pozzi[1], P. Radice[1]*

[1] ARIANET srl, Italy
[2] CNR ISAC Turin, Italy
[3]CNR ISAC Rome, Italy

**Abstract**: Shipping is a major source of global air pollution. This is mainly due to the actual ship propulsion largely based on diesel engines fed on medium to low refined oil. In near-port regions (particularly close to city-ports), the air pollution may represent an important air quality issue: annual average of pollutants may be increased by port activities and, in specific conditions, ship smokes can spread to the ground in high concentration transients, often leading to population concerns. In this work, we address the effects of source-specific emissions in the Civitavecchia port on regulated air quality indicators in a local scale domain surrounding the city. This goal is addressed by high-resolution simulations using a Lagrangian Particle Dispersion model, and in situ observations carried out by the air quality stations of the network continuously operated by the regional environmental agency. The study employs the 2018 meteorological and emission scenario as a reference to address, using the same meteorology, two further emission scenarios representing possible port developments. The first one assumes modifications to the ships' emissions produced by a shift to electric of a portion of the fleet calling at Civitavecchia in 2018, while the second one assumes both ship and land-side emissions changes derived from a shift to LNG propulsion of a given percent of the fleet, plus a shift from truck to train-based transport of some of the ground goods movements. The work estimates and examines in detail: 1) the naval and ground-based components of the port emission impact in all the scenarios; 2) their relative contribution to air quality indicators at different locations with respect to other emissions in the area; 3) the possible benefits or local worsening induced by alternative solutions aiming at improving the air quality in the city of Civitavecchia and most populated areas of the surrounding region.

***Key words:*** *Lagrangian Particle model, SPRAY, Ship Emissions, Port Emissions*

## INTRODUCTION

As a potential source of air pollution, port emissions can substantially contribute to worsen the air quality, with potentially critical effects on the surrounding inhabited areas. One of the reasons for this is due to the ship propulsion, often based on diesel engines using bunker oil as a primary fuel.

For example, looking at the EU-regulated NOx, PM2.5 and SOx, shipping (national+international) contributes respectively 19.5%, 8.4% and 11% to the total EU33 emissions (EEA, 2019). Consequently, shipping NOx represents an important contribution to this pollutant in the EU, but also the other pollutants cannot be neglected. In addition, other port-related emission must be considered.

The port of Civitavecchia is part of a medium-small city located in central Mediterranean (central Italy, NW of Rome on the Tyrrenian coast) handling more than 10 Mt of goods and registering about 4 million passengers per year. A number of ground services and transport were associated with the naval activities, including private and logistic automotive transport, diesel train deployment of goods, crane handling of goods. In a previous study it has been shown that at the city-port boundary, the annual share of regulated pollutants originating in the port area by shipping and ground movements is of 33% for PM10, 43% for $NO_2$, and 60% for $SO_2$. Additional analysis of pollutants that will be regulated within the forthcoming new EU Air Quality Directive (e.g. Black Carbon and ultrafine particles) showed the in-port high polluting potential of some ship categories (Gobbi et al., 2020). In order to provide a possible emission reduction and to study the effect of this reduction on the pollutant concentrations in the region surrounding the port, the Port Authority of Civitavecchia has envisaged a series of interventions involving both the naval movement and some of the land-based activities. The scope of this study is to understand, through the use of a dispersion model, the impact of the Civitavecchia port emissions on the air quality employing a meteorological and an emission scenario related to the entire year 2018, encompassing both the naval movements and land activities and considered as a reference (SC0) situation. The study then addresses, using the same meteorology, two further emission scenarios representing possible port developments. These are: 1) a scenario (SC1) assuming modifications to the ships' emissions determined by a shift to electric propulsion of a portion of the fleet calling at Civitavecchia in 2018, and 2) a further scenario (SC2), assuming both ship and land-side emissions modifications generated by a shift to LNG propulsion (of about 50% of the fleet), electrification of the port's service vehicles, plus a shift from truck to train-based transport of some of the ground goods movements.

Using the possibility offered by the use of a Lagrangian Particle Dispersion Model, it is possible to separate the different contributions to the total pollution generated by the port and induced by different port activities, thus assessing the related possible enhancements due to the alternative emission reduction scenarios. In this respect, the work examines both the naval and ground components of the port emissions in all the considered scenarios along with their relative contribution to Air Quality indicators at different locations in the Civitavecchia area, compared to the available measurements collected by the local network. In addition, the possible benefits or even specific local worsening generated by the alternative solutions defined through SC1 and SC2 are set in evidence, showing both their effect in terms of absolute ground-level concentrations of some of the regulated pollutant species and the related percentage of reduction.

## METHODS

### EMISSION SCENARIOS

As said, in 2018, the overall Civitavecchia port activities included the movement of about 4 million passengers, mostly associated with cruise and ferry transport. In addition, more than 11 Mt of goods were handled in the port including grain, forest products, steel products, chemicals, new cars and containers, in addition to liquid bulk. To build the reference SC0 scenario, a total of 643 ship-to-shore combinations, characterising the naval traffic during the 8760 hours of the year, have been considered. Starting from the information given by the local Port Authority (mainly the type of ships and related engine-fuel combinations), a bottom-up estimation of the emission has been done using a mix of Tier 2 and Tier 3 methodologies described in the European Emission Inventory Guidebook guidelines (EMEP/EEA, 2019). For landside emissions several types of sources have been considered, attributed to different sectors of activity, such as road vehicles related to cruise ships, cabotage, cargo, port operators or services and public transports, new cars to be shipped, cranes, rail transport of goods. For each of these sectors, emissions were estimated, when possible, by implementing the European COPERT 5.2.2 methodology. The first SC1 reduction scenario considers the same landside activities and emissions, the same ships of SC0 but a switch to electric for 32% of the cruise ships and two ferries during the manoevring and hotelling phases. The second SC2 scenario considers again the same ships of SC0 but with 50% of the cruise ships GNL powered. For landside activities, the port transports in SC2 are completely electric and an important switch to railway of the good transfer is considered, causing a general reduction of the emissions but a local sensible increase in the proximity of the train track layout due to the diesel engines. As an example, Table 1 reports the total annual emissions for NOx, $SO_2$ and PM10 in all the three scenarios, separated between naval and landside sectors, and the percentage of their reduction in SC1 and SC2 with respect to the reference scenario SC0.

**Table 1.** Total annual emissions in different scenarios for NOx, $SO_2$, PM10 and for different emission sectors

| **Specie/Sector** | **Scenario SC0 Annual emission t/year** | **Scenario SC1 Annual emission t/year** | **Scenario SC2 Annual emission t/year** | **% SC1-SC0** | **% SC2-SC0** |
|---|---|---|---|---|---|
| NOx/Naval | 1713 | 1498 | 1396 | -12.6 | -18.5 |
| NOx/Land | 47 | 47 | 58 | - | 23.4 |
| $SO_2$/Naval | 69 | 60 | 54 | -13.0 | -21.7 |
| $SO_2$/Land | 0.077 | 0.077 | 0.071 | - | -8 |
| PM10/Naval | 207 | 171 | 147 | -17.4 | -29 |
| PM10/Land | 2.84 | 2.84 | 3.20 | - | +13 |

To feed the high-resolution dispersion model, the emission of regulated pollutants (NOx, $SO_2$, CO, PM10, PM2.5and NMVOC) from the naval sources have been located on the trajectories followed by the ships (for both the manoevring and cruising phases) as linear sources, on the dock positions as point sources (for the hotelling phase). For the terrestrial sources, areal emissions related to the ground activities have been considered. All the emissions are considered on a hourly basis for the entire year 2018.

## NUMERICAL MODELLING

The dispersion of the pollutants released in the harbour area by the various emission sources in all the different scenarios has been reproduced using the 3D Lagrangian Particle Dispersion Model SPRAY (Tinarelli et al., 2000, Anfossi et al., 2010; Tinarelli, 2013). This was driven by the hourly 3D meteorological fields produced by the diagnostic SWIFT/Minerve code (Finardi et al., 1998) and the boundary-layer model SURFPRO (Silibello, 2006), downscaling on the target computational domain at the horizontal resolution of 100 m the information given at a larger scale by a meteorological simulation performed using the prognostic mesoscale WRF code on hourly basis for the entire year 2018. The computational domain considered is the 16 × 16 $km^2$ area illustrated in Figure 1. Both the port and the city of Civitavecchia are located in the central part of the domain along the coast, the city being located south of the port area. The figure shows also the position of the stations of the AQ network managed by the regional environmental authority, measuring different pollutant concentrations, to be compared with simulation results.

**Figure 1.** Computational domain (white rectangle) and stations of the local environmental network

## RESULTS

Ground level concentration fields of the considered primary pollutants have been produced by the simulation on a yearly basis, considering the meteorological scenario of the year 2018. The Lagrangian dispersion model allows the separation of the contributions generated by the different emission sectors in order to verify both their quantitative and spatial effect on the ground level concentrations. In this respect, Figure 2 shows as an example the annual average ground level concentration fields of NOx considering all the emissions (left) and the separation between naval sources (centre) and landside sources (right) in the baseline SC0 scenario. It is evident that the naval sources, encompassing all the phases related to the ships' activities, cover a large portion of the domain, with a relatively small quantitative contribution on the maxima compared to the one of the landside emissions. These last are evidently having a more local impact, but in a smaller portion of the domain. This is mainly due to both the geographical distribution of the naval sources and to the plume rise of their hot emissions determining a more spreaded dispersion in the considered area. A local concentration maximum of about 29 $\mu g/m^3$ for the annual average NOx concentration, mainly due to the landside emissions, represents a value below the limit of the current Italian legislation (40 µg/m$^3$ for the $NO_2$ component only) being anyway a non-negligible contribution due to the port emissions. The city of Civitavecchia is affected by lower concentration levels, with an absolute contribution of the port activities of the order of 2-3 µg/m$^3$.

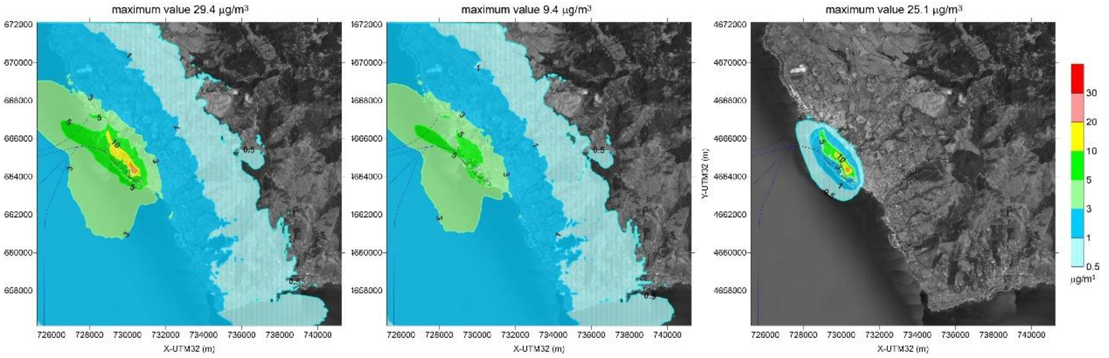

**Figure 2.** Annual average NOx ground level concentration fields, Emission scenario SC0. All the sources (left), contribution of naval emissions (centre), contribution of landside emissions (right).

To have an idea of the quantitative and spatial effects on the concentrations generated by the two alternative scenarios Figure 3 illustrates a detail of the annual average NOx concentration generated by only the landside emissions in the SC0 (left) and SC2 (centre) scenarios. It is evident a decrease in the concentration maximum, from 25.1 µg/m$^3$ to 23 µg/m$^3$, but some zones in the eastern part of the port area are characterized by a local increase of the concentrations, due to the increase in railway movements considered in the scenario SC2, since the trains have diesel engines. This is clearly illustrated in the rightmost panel of Figure 3, representing the area of decrease (from light green to blue) or increase (from orange to red) of the annual average concentrations.

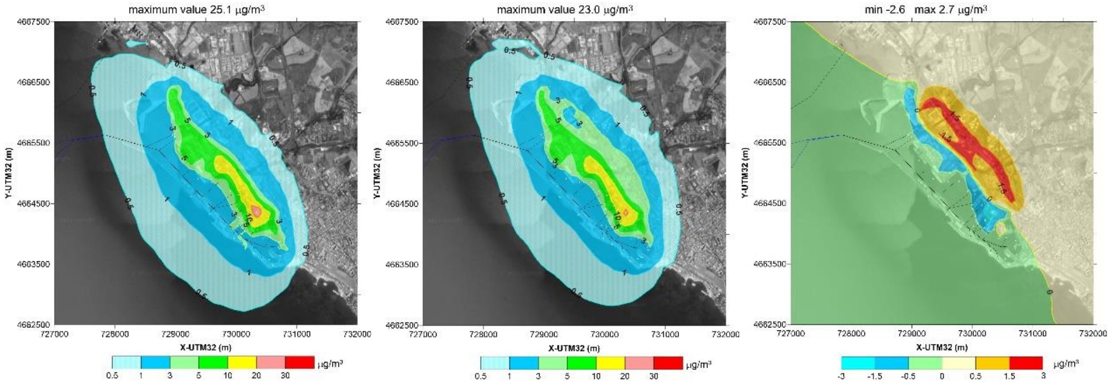

**Figure 3.** Zoom of the annual average NOx ground level concentration fields, contribution of the landside emissions, scenario SC0 (left) and SC2 (centre). Absolute difference SC2-SC0 (right).

Looking at the comparison on the domain with the measured data, Figure 4 illustrates, in the leftmost panel, the annual averages of NOx concentrations simulated at the positions corresponding to the measuring stations illustrated in Figure 1, generated by all the emissions in the three different scenarios. Apart the particular case of the Fiumaretta station, where the local impact of the change of railway emissions is high, when moving from the baseline SC0 scenario to the SC2 scenario there is a general decrement of the ground level NOx concentrations (the same for all the other considered species, not shown here). The local benefit in terms of NOx annual average concentrations is of the order of 2 µg/m$^3$ close to the port and 0.5-1 µg/m$^3$ farther. This corresponds to a larger decrease in the NOx annual average concentration with respect to the baseline value of around 4% at Civitavecchia Porto in the SC2 scenario (below 2% in the SC1 scenario) and of the order of 1-5%-2% at Civitavecchia and CV-Roma, two stations inside the urbanized area south of the port. The rightmost panel of Figure 4 shows the contribution in percentage, of the simulated concentrations due to port activities with respect to the average annual measured NOx concentrations, in the different scenarios. Close to the port, the contribution to the total concentrations is of the order of 30%, decreasing to less than 10% inside the city of Civitavecchia. Similar results are obtained for $SO_2$ while for PM10 the simulated port contributions are much lower, always less than 5% due to the fact that the model simulates only the primary component of the particulate matter while the AQ measurements include also the contribution of secondary PM10.

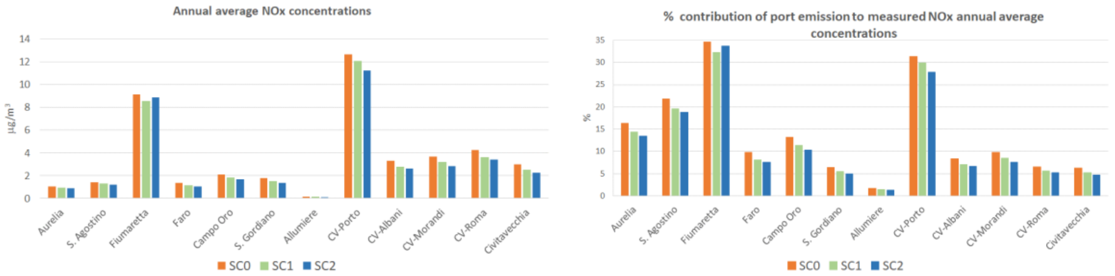

**Figure 4.** Annual average of NOx ground level concentrations simulated at the station positions of the local environmental network (left) and corresponding contribution to the measured concentrations (right)

## DISCUSSION

The work shows the significance of simulating the impact of the port emissions on the surrounding territory, particularly important in presence of populated regions. The use of a modelling approach allows to better understand both the spatial distribution of this impact, splitting the components due to different emission sectors, and the contribution of the port emissions with respect to the measured concentration values. In addition, it is possible to study the effectiveness of possible future interventions to the port activities aimed to reduce the emissions and the related impact. Specifically for the port of Civitavecchia, simulations show that the contribution of the port emissions to the measured concentrations can be significant in the vicinity of the port but still noticeable in the urban region located southern of the port itself. Emission reductions involving the use of electric or GNL policies for the ships can determine corresponding significant pollution reductions. For what concern the landside emissions, some attention must be paid to the way the modification of the port activities is implemented. For example a substantial shift towards the use of railways transport for the goods managed by the port could lead to local pollution increases, if not supported by the use of the electrical power supply instead of the thermal diesel one.

## REFERENCES

Anfossi D., Tinarelli G., Trini Castelli S., Nibart M., Olry C., Commanay J., 2010: A new Lagrangian particle model for the simulation of dense gas dispersion. Atmospheric Environment 44, 753-762.

EEA, 2019: Contribution of the transport sector to total emissions of the main air pollutants, https://www.eea.europa.eu/data-and-maps/daviz/contribution-of-the-transport-sector-6#tab-chart_4

EMEP/EEA, 2019: air pollutant emission inventory guidebook 2019-Technical guidance to prepare national emission inventories, EEA Report No 13/2019.

Finardi S., Tinarelli G., Faggian P. and Brusasca G., 1998: Evaluation of Different Wind Field Modeling Techniques for Wind Energy Applications over Complex Topography, Journal of Wind Engineering and Industrial Aerodynamics, **74-76**, 283-294, 1998.

Gobbi, G. P., Di Liberto, L., and Barnaba, F., 2020: Impact of port emissions on EU-regulated and non-regulated air quality indicators: The case of Civitavecchia (Italy). Science of the Total Environment, 719, 134984, https://doi.org/10.1016/j.scitotenv.2019.134984

Silibello C., 2006: SURFPRO (SURrface-atmosphere interFace PROcessor) User's guide, ARIANET report R2006.06.

Tinarelli G., Anfossi D., Bider M., Ferrero E. and Trini Castelli S., 2000: A new high performance version of the Lagrangian particle dispersion model SPRAY, some case studies. Air Pollution Modelling and its Application XIII, Gryning S.E.and Batchvarova E. Eds., Plenum Press, New York, 23, 499-506.

Tinarelli G., 2013: SPRAY 3.1.10, General description and User’s Guide, ARIANET report R2013.27.