IMPACT OF ATMOSPHERIC EMISSIONS FROM SHIPS IN PORT ON URBAN AREAS

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Maritime transport, despite being one of the most efficient modes of transport, causes several major environmental problems, particularly about air pollution. Furthermore, due to the growth of shipping activities, its environmental impact will be more relevant in the future. Because of the current environmental issues, the legislation on shipping emissions is frequently updated and becomes more and more stringent. Several policies were issued in the last decades, mainly focused on reducing the content of sulfur in marine fuels. The last international IMO-2020 regulation was enforced on 1 January 2020, it limits the sulfur content of any fuel oil used on board ships at a maximum of 0.50% m/m (mass by mass) outside emission control areas (ECAs) and 0.1% inside ECAs. Since 1 January 2021, in the Baltic and North Sea a nitrogen emission control area (NECA) was applied, requiring the ships built after 2021 operating in this area must respect a mandatory Tier 3 standard (80% reduction compared to Tier 1). The establishment of ECAs has become an important measure to reduce and control ship emissions. Even though, in-port emissions account for a relatively small proportion of the total emissions due to shipping, they can represent a significant impact on the health of population living in port cities and coastal areas. To accurately quantify the risk associated with atmospheric emissions of ships when in-port and the potential benefits of control measures, it is necessary to improve the state-of-art of both the estimation of emissions and the performance of atmospheric dispersion models.

The aim of this thesis is to assess the impact of ship emissions in the port of Naples in 2018 by the development of a bottom-up procedure improving the state-of-art of present methodologies. Pollutants considered are NOx, SO2 and PM10. The developed methodology can be applied to any port.

The first issue analyzed in this thesis is the validation and the optimization of CALPUFF model when used to simulate the dispersion of the ship emissions in a port. With this aim wind tunnel tests and Computational Fluid Dynamics (CFD) numerical simulations were used to model the dispersion of atmospheric emissions of cruise ships at hoteling in the port of Naples. A part of the Naples urban area large about 1.2 km2 was reproduced at a scale of 1:500 for the wind tunnel experiments (Figure 1). The worst emission scenario with three cruise ships emitting at the same time and wind blowing from the south-east with a speed at funnel height of 3 m/s in neutral stability conditions of the atmospheric boundary layer was studied. Two different values UR=1 and UR=4 of the ratio funnel gas velocity/wind speed were considered. In the wind tunnel experiments, Ethane was used as the tracer gas and its concentration was measured at 35 receptor points inside the urban area and at different heights.

Figure 1. The reduced-scale physical model of the port of Naples realized in the wind tunnel at the Ecole Centrale de Lyon.
The dispersion of ship emissions in the same area was also studied by CFD simulations using steady-state solutions of the RANS equations with a $k-\omega$ shear-stress transport (SST) turbulence model. A very good agreement between wind tunnel and CFD results is observed. The same simulations were then performed with CALPUFF. The results were used to analyze the accuracy of the predictions of the dispersion model CALPUFF. The effect of two CALPUFF model options was studied: the building downwash module and the parameterization of the dispersion coefficients. The CALPUFF results are less accurate than the CFD simulations and show a general tendency to underestimate the experimental data. However, the optimization process improves the performance of CALPUFF. A more comprehensive analysis of the effect of a varying UR in the range 0.25 – 16 was also undertaken using numerical models.

The second step was the creation of a comprehensive global data base of all ships visiting the port of Naples in 2018. Using AIS data a data base containing the main information of more than 900 ships (category, name, IMO number, gross tonnage, deadweight; length, width, draft, total power installed onboard and the type of engines; maximum speed; the number of passengers, cars, containers) was created. All ships were lumped in 45 categories and five macro-categories (Commercial, Fishery, Passenger, Tanker, and Other). To fill the missing data, regressions based on real data for each category were adopted.

Once created this “static” database, AIS data were processed through a MATLAB code which is able to identify the phase of ships on the basis of the analysis of the temporal data, of the time delta between records, and of the speed data. The phases defined are as follows: entry to the port, navigation in the port, the start, stop, and end phases of mooring at the quay, exit from the port, and engine start and stop. In this way at each AIS record is associated a specific activity-phase of the ship. Once all this information was completed, emission rates of NOx, SO2, and PM were calculated. Great accuracy was applied to the evaluation of the real power of main engines starting from the average speeds when ships are moving in port with respect to that using the typical load factors corresponding to the cruise phase. Similar accuracy was also applied to the evaluation of the total power of auxiliary engines both during the navigation and hoteling phases. The reference adopted is the recent EMEP/EEA guideline using specific emission factors defined for each category of ships and activity phase.

AIS data were also used to identify in and out routes and mooring piers for each ship category. For the sake of simplicity piers and routes were merged when very close each other. In parallel to this approach, typical of bottom-up procedures, a statistical study based on data from 38 ports all over the world in 45 annualities was performed with the aim to correlate emissions with traffic data per year. Traffic data considered are: number of passengers, hours spent in each phase, number of calls for passenger ships; and tons of good, hours spent in each phase and number of calls for commercial ships. The correlation with traffic data gives the possibility of an easy check of the emissions estimated but show, as expected, a certain degree of uncertainty. Once verified and optimized the accuracy of CALPUFF simulations, the complete emission inventory developed for the port of Naples was used as input to CALPUFF together with meteorological data. The results of simulations were compared with data from fixed monitoring stations in the urban area both as annual average and percentile. In this way the impact of ship emissions on air quality in Naples in 2018 was assessed.

The research provides at the same time useful insights on the contribution of ship emissions to air pollution in Naples and on an accurate procedure to assess the impact of ship emissions in port cities.

References:


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