Evaluation of sulfur dioxide in air quality from the emissions of vessels anchored in the Port of Rio de Janeiro, Brazil

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Abstract. The navigation of waterway transport has increased significantly in the last decades in the world and Brazil contributes to this growth. Supply boat types used for logistical support the platforms demand the consumption of high-density oil for the propulsion of the main engines, auxiliaries, and boilers, which result in continuous emission of pollutants into the atmosphere, today considered one of the biggest polluters. Recent studies estimate the emission of pollutants up to 400 km from the coast, which demonstrates the direct impact on coastal communities. One way to assess the impact of these emissions is to use mathematical models that allow the effects of air pollutants to be calculated on the environment and in coastal regions, being a relevant tool for planning and regulation purposes. The main objective of this work was to provide an estimate calculation of sulfur dioxide emissions from vessels that are anchored in Guanabara Bay, Rio de Janeiro, Brazil, and understand the relative contribution of this pollutant in the context of its neighborhood. After the simulations, some calculations obtained were compared with the values monitored in nearby region, in order to estimate the contribution of sulfur dioxide emission in this region. The estimated contribution of sulfur dioxide in the evaluated region, varied from 1% to 80% from the comparisons with the monitored data.

1. Introduction
The emission of compounds into the atmosphere from vessels is one of the current problems of the international scientific community, as it is a growing problem, due to the increase in maritime transport in the world. Recent studies have estimated that approximately 8% of global anthropogenic emissions of sulfur dioxide (SO₂) come from maritime transport and that approximately 70% of emissions from vessels occur 400 km offshore [1], indicating the significant impact of these emissions on coastal areas. The atmospheric emissions are generated mainly due to the power of the propulsion installation of the vessels, whereas in any combustion system, the marine engines burn a fuel derived from oil to release energy and the SO₂ emissions are due to the high sulfur content present in the fuel, used by most ocean vessels [2].

In Brazil, the majority of vessels are of the tug, supply boat and speedboat type and represent the largest quantity authorized for maritime support navigation and the main classes of the Brazilian supply boat fleet are the anchor handling tug supply (AHTS) and the platform supply vessel (PSV); diesel powered vessels are significant and growing sources of pollution, both locally and globally. With the expectation of an increase in the flow of vessels in the organized area in the Port of Rio de Janeiro, Brazil, due to the prospecting of the pre-salt, it is necessary to measure pollutant emissions and the corresponding environmental impact that supply boats may have on air quality in the around Guanabara Bay.
In this sense, it is very important to carry out an inventory of the total number of offshore and supply boats that anchor in the areas of interest in Guanabara Bay, Rio de Janeiro, Brazil, as well as their technical and operational characteristics and to model atmospheric concentrations in order to understand their variations according to meteorological parameterization of various scenarios, establishing an emission model applicable to the problem, identifying and estimating the percentage of contribution of pollutants in their regions directly affected.

2. Materials and methods

2.1. Emissions data

This study was carried out in Guanabara Bay, Port of Rio de Janeiro, Brazil; located on the coast of the State of Rio de Janeiro, Brazil, it is considered as one of the most sheltered bays in the world [3]. The data collection for this study was based on all seasons of the year 2017, with the counts of the supply boat type and the geographical coordinates of the ships that were anchored in the region through marine traffic being carried out. The study areas are represented by 2F06 and 2F6A, as well as their coordinates, according to the specification of the Nautical Chart of Guanabara Bay, Rio de Janeiro, Brazil, presented respectively, in Figure 1 [4] and Table 1 [5]. SO$_2$ was monitored using a SO$_2$ analyzer by ultraviolet fluorescence and it was located at Federal University of Rio de Janeiro, Brazil; the SO$_2$ monitored to compare with the calculated ones of the modeling was necessary, because in this way we obtained greater reliability and continuous data. Whereas that the monitoring stations of the environmental agency do not always obtain monitored SO$_2$ results.

![Figure 1](image_url)

**Figure 1.** Study area, Port of Rio de Janeiro, Brazil. Adapted from the website Marine Traffic Live Ships Map.
Table 1. Anchored areas used to delimit the areas evaluated in this study obtained from Guanabara Bay nautical chart, Rio de Janeiro, Brazil.

| Coordinates | 2F06 | 2F6A |
|-------------|------|------|
| Longitude   | Latitude | Longitude | Latitude |
| 22°50.46'S | 043°12.08'W | 22°51.07'S | 043°09.07'W |
| 22°50.46'S | 043°11.12'W | 22°49.86'S | 043°08.85'W |
| 22°50.99'S | 043°10.73'W | 22°49.86'S | 043°08.63'W |
| 22°50.99'S | 043°09.62'W | 22°49.25'S | 043°08.62'W |
| 22°51.86'S | 043°09.62'W | 22°49.25'S | 043°07.81'W |
| 22°51.67'S | 043°11.98'W | 22°49.81'S | 043°07.49'W |
| 22°51.07'S | 043°12.16'W | 22°50.96'S | 043°07.79'W |

2.2. Atmospheric dispersion modelling study
Dispersion modelling uses mathematical formulations to characterize the atmospheric process that disperse a pollutant emitted by a source, based on emission rate, source data and meteorological inputs. For this study was utilized the software AERMOD, a commercial atmospheric dispersion model recognized by United States Environmental Protection Agency (US EPA). AERMOD is a steady-state commercial model that allows the calculation of the concentration of a given pollutant from multiple sources, it considers the Gaussian model for plume dispersion for stable atmospheric conditions. AERMOD software has two data processors: (i) AERMET, a meteorological data preprocessor, and (ii) AERMAP, a terrain data preprocessor; this allows the model to consider the effects of surface and elevated sources, and also differentiation of simple and complex terrains [6]. Coefficients \(\sigma_y\) and \(\sigma_z\) were defined using McElroy-Pooler urban fit and Pasquill-Guifford stability class (A/B, C, D, and E/F) [7].

2.3. Emissions calculation
For the calculation of \(\text{SO}_2\) emissions, the proposed model was considered by [8], since it proved to be viable due to accessibility of the data required for the model input and is given by the following Equation (1).

\[
E = [A]x[B]x[T]x[F],
\]  

where \([A]\) = [gross tonnage], \([B]\) = [fuel consumption], \([T]\) = [time], and \([F]\) = [emission factors]. Compilation of air pollutant emission factors has been a benchmark on emission factors. Application of emission factors available in AP-42, US EPA [9], for different industrial processes is a recurring practice and shows adherence if compared to experimental data when this comparison is possible.

2.4. Meteorological data
Meteorological data comprising wind, temperature, and relative humidity from January 2017 to December 2017 were collected from meteorological stations placed near the Port of Rio de Janeiro, Brazil. Other meteorological variables such as solar radiation, accumulated precipitation in 24 h and cloud cover were obtained from the National Institute of Meteorology conventional and automatic meteorological stations, both located in the nearby city of Rio de Janeiro, Brazil [10].
3. Results and discussion

3.1. Meteorological parameters
For the modeling, the following surface meteorological information was needed to estimate local parameters, that is: air temperature (°C), atmospheric pressure (hPa), wind speed (ms⁻¹), wind direction (degrees), air humidity (%), solar radiation (Wm⁻²) and precipitation (mm). The meteorological data applied to the Guanabara Bay region were made available by the Weather Forecast and Climate Studies Center for the weather station at Antônio Carlos Jobim Airport, Rio de Janeiro, Brazil, except for solar radiation data, which were extracted from the website of the National Meteorological Institute [11]. Wind roses generated for one year are shown in Figure 2.

![Wind roses station by season](image)

**Figure 2.** Wind roses station by season for the region select for analysis for one year.

It was observed that the constructed wind roses presented the daily directions and the frequencies of the winds occurring predominantly in the following ways: Spring - southeast, south, and east direction; Summer - northwest, southwest and southeast; Autumn - west and northwest, and Winter - northeast and east.

3.2. Modeling results
The results of the dispersion model were calculated under different atmospheric conditions. The worst simulated scenarios are presented in Figure 3, Figure 4, Figure 5, and Figure 6 with the maximum hourly concentrations calculated for SO₂.
Figure 3. Maximum hourly concentration of \( \text{SO}_2 \) calculated during the spring season.

In this season of the year, 40 supply boat vessels anchored in the Port of Rio de Janeiro, Brazil, were considered and the maximum calculated concentration was 30.2 \( \mu \text{gm}^3 \) and the monitored concentration was 45.3 \( \mu \text{gm}^3 \). The estimated average concentration of ships in the area monitored at this time of year was 58.0%.

Figure 4. Maximum hourly \( \text{SO}_2 \) concentration calculated during the summer season.

In this station, 35 supply boat vessels anchored in Porto of Rio de Janeiro, Brazil, were considered and the maximum concentration calculated was 50.4 \( \mu \text{gm}^3 \) and the monitored was 86.4 \( \mu \text{gm}^3 \). The estimated average concentration of ships in the monitored area at this time of year was 23.5%.
Figure 5. Maximum hourly concentration of SO$_2$ calculated during the autumn season.

In this season of the year, 36 supply boat vessels anchored in Port of Rio de Janeiro, Brazil, were considered and the maximum calculated concentration was 11.0 $\mu$gm$^{-3}$ and the monitored was 30.5 $\mu$gm$^{-3}$. The estimated average concentration of ships in the monitored area at this time of the year was 43.0%.

Figure 6. Maximum hourly SO$_2$ concentration calculated during the winter season.

In this season of the year, 35 supply boat vessels anchored in Port of Rio de Janeiro, Brazil, were considered and the maximum calculated concentration was 100.4 $\mu$gm$^{-3}$ and the monitored one was 86.4 $\mu$gm$^{-3}$. The estimated average concentration of ships in the monitored area at this time of the year was 80.2%.
4. Conclusions
In general, this work estimated the SO₂ emission of supply boats anchored in the Port of Rio de Janeiro, Brazil, in a single location, but it is important to note that from these results, it was verified that the estimates of the vessels’ contributions were relevant in the simulated analyzes. Such indication could be an alert for the environmental agencies to consider, especially, when they are going to carry out the inventories of atmospheric emissions in the Metropolitan Region of Rio de Janeiro, Brazil, and other cities with the same characteristic and expanding to all metropolitan region monitoring stations so that we can have a more accurate estimate of the contribution of emissions from this and other pollutants emitted from vessels anchored in the Port of Rio de Janeiro, Brazil. It is important to note that all emissions calculated and monitored were below the limits established by “Ministério do Meio Ambiente, Conselho Nacional do Meio Ambiente (CONAMA)” Resolution No. 419 of 2018 [12].

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