17th Conference on

Computer and IT Applications in the Maritime Industries

# COMPIT'18

Pavone, 14-16 May 2018

**17th International Conference on**

**Computer and IT Applications in the Maritime Industries**

# COMPIT'18

**Pavone, 14-16 May 2018**

Edited by Volker Bertram

Technische Universität Hamburg-Harburg
Institut für Entwerfen von Schiffen und Schiffssicherheit
Schwarzenbergstraße 95 Gebäude C D-21073 Hamburg

TUHH Technologie GmbH

## Sponsored by

www.dnvgl.com

www.ssi-corporate.com

www.siemens.com/marine

www.sarc.nl

www.foran.es

www.aveva.com

http://intens.vtt.fi

www.friendship-systems.com

www.krs.co.kr

www.prostep.com

**17th International Conference on Computer and IT Applications in the Maritime Industries**, Pavone, 14-16 May 2018**,** Hamburg, Technische Universität Hamburg-Harburg, 2018, ISBN 978-3-89220-707-8


Schriftenreihe Schiffbau
Schwarzenbergstraße 95c
D-21073 Hamburg
http://www.tuhh.de/vss

## Index


Volker Bertram, Tracy Plowman 7
*Virtual Reality for Maritime Training – A Survey*

Volker Bertram 22
*Demystify Artificial Intelligence for Maritime Applications*

Donald MacPherson 36
*A Highly-Efficient Propeller Actuator Disk Replacement*

David Andrews 44
*Does the Future Ship Designer Need to be a Human Factors Expert?*

Riccardo Cassetta, Jan O. Fischer 55
*Parametric Cost Estimation at Azimut Yachts*

Agnes U. Schubert, Michael Gluch, Knud Benedict, Hendrik Kupas, Olaf Hagendorf, Olaf Simanski 61
*Conception of Navigation Assistance System Integrating New Sensor Technologies and Model-based Prediction*

Jing Xie, Geir Hamre, Erik Stensrud, Bahman Raeissi 69
*Automated Crack Detection for Drone-based Inspection Using Convolutional Neural Network*

Auke van der Ploeg, Bart Schuiling 84
*Improving an Already Optimized Ship by Making its Stern Asymmetric*

Denis Morais, Mark Waldie, Darren Larkins 98
*The Digital Twin Journey*

Myeong-Jo Son, Joung-Hyun Lee, Ho-Gyun Park, Jeong-Youl Lee 106
*Mobile Visualization for Finite Element Model and Assessment Result of Whole Ship*

Ulrike Moser, Ole Christian Astrup 116
*Approaching Design Review by Classification Society based on Digital Information Derived from the Customer's Design Models*

Thomas Koch, Konstantin Kreutzer, Andreas Roppelt 132
*Cloudless Skies in Early Design?*

Christos Gkerekos, Iraklis Lazakis, Stylianos Papageorgiou 144
*Leveraging Big Data for Fuel Oil Consumption Modelling*

Kohei Matsuo 153
*Technology Mega Trends That Will Change Shipbuilding*

Gunawan, Kunihiro Hamada, Kazetaro Ouchi, Hiroyuki Yamamoto, Yoichi Sueshige 163
*Optimization of Part Arrangement in Engine Room*

Nikolaj Meluzov, Axel Friedewald 176
*Modular Authoring of Augmented Reality Based Service Instructions*

Maricruz A.F. Cepeda, Gabriel P. Monteiro, João V.M. de Oliveira Moita, Jean-David Caprace 189
*Estimating Ship Emissions Based on AIS Big Data for the Port of Rio de Janeiro*

Lukas Niepert, Matthias Grau 204
*Model-Based Class Approval and Site Inspection*

Anna Friebe, Giammarco R. Casanova, Maël Le Gallic, Clément Rolinat, Matias Waller 211
*Situational Awareness and Obstacle Avoidance for a Wind Propelled Marine Research ASV*

Bastiaan Veelo, Herbert Koelman 226
*Fitting Watertight NURBS Patchworks over Irregular Curve Networks with LEANURBS*

Stephan Procee, Clark Borst, René van Paassen, Max Mulder 237
*Using Augmented Reality to Improve Collision Avoidance and Resolution*

Woo-Sung Kil, Myeong-Jo Son, Jeong-Youl Lee 250
*Development of Multi-Purpose VR Simulator for a Ship from 3D CAD Model*

Chris Lewis 259
*Bee-Swarm Inspired Cooperative Robotics and Augmented Reality for Seafloor Exploration*

Yong-Kuk Jeong, Jong Hun Woo, Philippe Lee, Youngmin Kim, Young-Ki Min, Jong Gye Shin, Yong Gil Lee, Cheolho Ryu 265
*Shipyard DES Simulation Framework and its Applications*

Jong Hun Woo, Jaeho Choi, Ji Hye Kim, Young-Kuk Jeong, Philippe Lee, Jong Ho Nam 271
*Machine Learning in Ship Production*

Guillaume Jacquenot, Jean-Jacques Maisonneuve, Damien Laval, Yann Bouju 284
*Virtual Reality in the Field of Numerical Marine Simulation*

Stefan Harries, Konrad Lorentz, Jörg Palluch, Eckhard Praefke 292
*Appification of Propeller Modeling and Design via CAESES*

Marius Brinkmann, Mohamed Abdelaal, Axel Hahn 308
*Vessel-in-the-Loop Architecture for Testing Highly Automated Maritime Systems*

Anne Fischer, Jan Sender, Daniel Roisch, Wilko Flügge 322
*Capturing As-Built Building Progress Data for Efficient Control of Outfitting Processes in Shipbuilding*

Jukka Merenluoto 331
*One Sea: Steps Towards Autonomous Maritime Operations*

Andrea Orlandi, Riccardo Benedetti, Riccardo Mari, Luigi Costalli 341
*Sensitivity Analysis of Route Optimization Solutions on Different Computational Approaches for Powering Performance in the Seaway*

Stein Ove Erikstad 354
*Design Patterns for Digital Twin Solutions in Marine Systems Design and Operations*

Ali Ebrahimi, Per Olaf Brett, Jose Jorge Garcia 364
*Fast-Track Vessel Concept Design Analysis (FTCDA)*

# Estimating Ship Emissions Based on AIS Big Data for the Port of Rio de Janeiro

**Maricruz A. F. Cepeda,** COPPE/UFRJ, Rio de Janeiro/Brazil, maricruzcepeda@oceanica.ufrj.br
**Gabriel P. Monteiro,** PENO/UFRJ, Rio de Janeiro/Brazil, gabriel_premolimonteiro@poli.ufrj.br
**João V. M. de Oliveira Moita,** COPPE/UFRJ, Rio de Janeiro/Brazil, joaov@poli.ufrj.br
**Jean-David Caprace,** COPPE/UFRJ, Rio de Janeiro/Brazil, jdcaprace@oceanica.ufrj.br

**Abstract**

*Automatic Identification System (AIS) data stores huge quantity of information regarding the safety of ships and port facilities in the international maritime transport sector. However, this big database is not only useful for the security of ships operations and port facilities. It can also be helpful for other important functions in maritime traffic such as reducing environmental impacts. This study develops an analytical approach to quantify ship emissions in the Guanabara Bay of Rio de Janeiro (Brazil) using AIS database. The model is applied to quantify Green House Gas (GHG) emissions trough the assessment of fuel consumption calculated for each individual vessel. The results shows that the proposed methodology is efficient to estimate total ship emissions over Rio de Janeiro Port area and Guanabara Bay. We suggest that quantifying the amount of emissions from ships in order to fulfil IMO regulations and reduce the health impacts of people who are living in surrounding areas of high maritime traffic is important for decision makers and for the maritime authorities.*

## 1. Introduction

Every day, more than 2.5 quintillion bytes of data are created. This is known as big data, the datasets whose size and structure is beyond the ability of typical programming tools to data collection, store, manage and analyses in a reasonable time and exceed the capacity of their perception by a human, *Zicari (2014), Miloslavskaya and Tolstoy (2016).*

Big data is present in key sectors and it has revolutionized the industry over the past several years. Companies across the various travel and transportation industry segments as airlines, airports, railways, freight logistics and others have been handling large amounts of data for years. In addition, today's advanced analytics technologies and techniques enable organizations to extract insights from data with previously unachievable levels of sophistication, speed and accuracy, *IBM (2014)*. Nowadays, big data is getting popular in shipping where large amounts of information is collected to better understand and improve logistics, emissions, energy consumption and maintenance. Using satellite navigation and sensors, trucks, airplanes or ships can be tracked in real-time. In shipping, the automatic identification system (AIS) and vessel traffic services (VTS) are mainly used to prevent collisions at sea. However, storing this information in data warehouse for a certain period allows the scientist to extract hidden knowledge from this bulk.

In early 2017, the ship world commercial fleet grew by 3.15% and reached a total of 1.86 billion DWT that consisted of 93161 vessels including bulk carriers, oil tankers, general cargo ships, container ships and others. Consequently, it produces a major marine traffic and a growth of fuel consumption contributing to global Green House Gas (GHG) emissions at sea impacting the climate change, *UNCTAD (2017)*. Ship emissions as a source of air pollution have been outlined in various studies worldwide, *Cooper (2003), Dalsoren et al. (2009)*. The GHG emissions of ship engines have raised the concern of International Maritime Organization (IMO) on the consequences for environment and human health. IMO first adopted MARPOL Annex VI in 1997. At present, IMO limits the main air pollutants in ships exhaust gas (sulphur oxides $SO_X$, nitrous oxides $NO_X$, Particulate Matter (PM), and Volatile Organic Compounds (VOC) emissions from tankers). It also regulates shipboard incineration, and prohibits deliberate Ozone Depleting Substances (ODS) emissions. IMO introduces Emission Control Areas (ECA), and it defines the energy efficiency design index (EEDI) and ship energy efficiency management plan (SEEMP). These regulations aim to reduce emissions and increase ship energy efficiency.

Some authors focused their research in emissions calculation in various regions around the world. In this study, we identify three locations of the emission evaluations. The first devoted to assess the emissions in oceanic navigation. The second devoted to the evaluation of emissions in coastline and inland waterways. The last one focusing on emissions around ports, Table I. However, the emissions studies in the literature are mostly located in Europe and Asia, opening a gap for studies on emissions in South America.

Since 2009 studies about emissions are presented in literature, the first developments are in Turkey by the same group of researchers, *Deniz and Kilic (2009), Deniz et al. (2010), Kilic and Deniz (2010).* These studies are about the estimation of shipping emissions in Candarli Gulf, Izmit Gulf and in the region of Ambarli port, the amounts of emission from ships can be calculated with the activity-based emission model.

*Nunes et al. (2017)* reviewed 26 papers about emissions calculations since 2010. In the majority of the cases the calculation of emissions are in port and during anchoring, most authors attributed that to container ships. Almost of studies reviewed are in Europe and Asia.

*Styhre et al. (2017)* analyzed the level of greenhouse gas (GHG) emissions from ships in port based on annual data from four ports in four continents (Gothenburg, Long Beach, Osaka and Sydney). They established that the potential to reduce emissions in a port area depends on how often a ship revisits a port. Also in this study, South America is not considering.

*Heitmann and Petersen (2014)* analyzed how much the shipping sector could contribute to efficient global $CO_2$ emission reductions and thus could always achieve global cost savings. *Fan et al. (2016)* study the emission factors of domestic vessels and ocean-going vessels and the potential impact of ship emissions on the surrounding atmospheric environment. They concluded that ship emissions have a significant impact on the entire Yangtze River Delta region and on greater East China. Moreover, *Winnes et al. (2015)* quantified the potential reductions of ships GHG emissions from efforts implemented by the port of Gothenburg.

From this state of the art review, five different methods to assess the emissions has been identified. The main equations have been related below whereas Table I: specify which method is used in each related publication.

$$\boldsymbol{E_{CO_2} = \frac{D}{V}\times\left(\%MCR\times RP\times SFOC\times EF_{CO_2}\right)_{ME} + \frac{D}{V}\times\left(\%MCR\times RP\times SFOC\times EF_{CO_2}\right)_{AE}} \quad (1)$$

| | | |
|---|---|---|
| Where, | $\boldsymbol{E_{CO_2}}$ | is the total emission of $\boldsymbol{CO_2}$ over the journey in kilograms (kg); |
| | $\boldsymbol{D}$ | is the total distance travelled on the journey in nautical miles (nm); |
| | $\boldsymbol{V}$ | is the average cruising speed of the vessel in knots (kn=nm/hr); |
| | $\%\boldsymbol{MCR}$ | is the average load on the particular engine as a fraction of the total installed power of the particular engine. $\boldsymbol{MCR}$ stands for 'maximum continuous rate'. |
| | $\boldsymbol{RP}$ | is the maximum rated power of the main or auxiliary engines in kilowatts (kW); |
| | $\boldsymbol{SFOC}$ | is the specific fuel-oil consumption rate of the engine in kg of fuel per kilowatt-hour of engine output (kg/kWh); |
| | $\boldsymbol{EF_{CO_2}}$ | is the emission factor for $\boldsymbol{CO_2}$ for the fuel type used by the main or auxiliary engines in kg of $\boldsymbol{CO_2}$ emitted per kg of fuel burnt; |
| | $\boldsymbol{ME}$ | is the main engines of the vessel; |
| | $AE$ | is the Auxiliary engines of the vessel. |

$$\boldsymbol{E_{At\,Sea} = D\times[ME\times LF + AE\times LF]\times EF_{At\,Sea}/V} \quad (2)$$

| | | |
|---|---|---|
| Where, | $\boldsymbol{E_{At\,Sea}}$ | is the total emission in grams (g); |
| | $\boldsymbol{D}$ | is the total distance travelled by ship in nautical miles (nm); |
| | $\boldsymbol{V}$ | is the speed of the vessel in knots (kn=nm/hr); |
| | $\boldsymbol{ME}$ | is the main engine load in kilowatts (kW); |
| | $\boldsymbol{AE}$ | is the auxiliary engine load in kilowatts (kW); |

| | | |
|---|---|---|
| | $\boldsymbol{LF}$ | is the load factor (%); |
| | $\boldsymbol{RP}$ | is the maximum rated power of the main or auxiliary engines in kilowatts (kW); |
| | $\boldsymbol{EF_{At\,Sea}}$ | is the emission factor. |

$$\sum \boldsymbol{E_{ikms}} = \boldsymbol{t_{km}} \times \boldsymbol{P_{kms}} \times \boldsymbol{EF_{ims}} \tag{3}$$

| | | |
|---|---|---|
| Where, | $\boldsymbol{E_{ikms}}$ | is the emission mount of pollutant which occurs from machine k of s type of ship during the operation mode m; |
| | $\boldsymbol{t_{km}}$ | is the running time of $k$ machine working on $m$ operation mode; |
| | $\boldsymbol{P_{kms}}$ | is the power of the k machine defined by the type and the gross tonnage of the ship; |
| | $\boldsymbol{EF_{ims}}$ | is the specific emission amount of engine depending on the ship type and operation mode. |

$$\textbf{Equation 1: } \boldsymbol{E_i} = \sum_{jklm} \boldsymbol{S_{jkm}(GT)} \times \boldsymbol{t_{km}} \times \boldsymbol{F_{ijklm}}$$

| | | |
|---|---|---|
| Where, | $\boldsymbol{E_i}$ | is the total emission of pollutant $i$; |
| | $\boldsymbol{S_{jkm}(GT)}$ | is the daily consumption of fuel $j$ in ship class $k$ in mode $m$ as a function of gross tonnage; |
| | $\boldsymbol{t_{km}}$ | is the days in navigation of ships of class $k$ with engine type $l$ using fuel $j$ in mode $m$; |
| | $\boldsymbol{F_{ijklm}}$ | is the average emission factor of pollutant $i$ from fuel $j$ in engine type $l$ in mode $m$ (detailed average emission factor). |

The last methodology identified is the ship traffic emission assessment model (STEAM) developed by *Jalkanen et al. (2009)* in their studies around the Baltic Sea area. The model is based on AIS data and uses some algorithms to estimate the emissions with the IMO curves for $NO_X$ emissions as well as for the prediction of $PM_{10}$, $PM_{2.5}$, $SO_2$ and $CO_2$ emissions.

Table I identifies each study, including information about year of publication, the authors involved, the methodology used based on the above detailed equations, the application zone of the methodology, the continent, and the location (1: oceanic navigation, 2: coastline and inland navigation, 3: ports).

Table I: Summary of the state of the art related to ship emissions assessment

| **Title of the study** | **Year** | **Reference** | **Methodol-ogy** | **Application zone / Conti-nent** | **Group** |
|---|---|---|---|---|---|
| Carbon emissions from international cruise ship passengers' travel to and from New Zealand | 2010 | *Howitt et al. (2010)* | Eq. 1 | New Zealand / Oceania | 1 |
| Estimation of shipping emissions in Candarli Gulf. Turk. | 2010 | *Deniz et al. (2010)* | Eq. 2 | Candarli Gulf, Turk / Europe | 2 |
| Inventory of shipping emissions in Iz-mit Gulf, Turkey | 2010 | *Kilic and Deniz (2010)* | Eq. 3 | Izmit Gulf, Tur-key / Europe | 2 |
| Estimation of Exhaust Emissions of Marine Traffic Using AIS Data (Case Study: Madura Strait Area, Indonesia) | 2010 | *Pitana et al. (2010)* | Eq. 4 | Madura Strait area / Oceania, Asia | 2 |
| Estimation of exhaust emission from ocean-going vessels in Hong Kong | 2012 | *Yau et al. (2012)* | Eq. 4 | Hong Kong / Asia | 1 |
| A Comprehensive Inventory of the Ship Traffic Exhaust Emissions in the Baltic Sea from 2006 to 2009 | 2013 | *Jalkanen et al. (2013)* | STEAM | Baltic sea / Eu-rope | 2 |
| Atmospheric emissions of European SECA shipping: long-term projections | 2013 | *Kalli et al. (2013)* | STEAM2 | Baltic sea, the North sea, and the English channel / Eu-rope | 2 |
| Policy change driven by an AIS-as-sisted marine emission inventory in Hong Kong | 2013 | *Ng et al. (2013)* | Eq. 3 | Hong Kong | 1 |
| Ships in a city harbour: An economic valuation of atmospheric emissions | 2013 | *McArthur and Osland (2013)* | Eq. 2 | Port Ofbergen in Norway / Eu-rope | 2 & 3 |
| Emission inventories for ships in the arctic based on satellite sampled AIS data | 2014 | *Winther et al. (2014)* | Eq. 1 | Artic area north of 58.95n / ECA | 1 |

| | | | | | |
|---|---|---|---|---|---|
| An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet | 2015 | *Coello et al. (2015)* | Eq. 4 | UK fishing fleet / Europe | 2 |
| Methodologies for estimating shipping emissions and energy consumption: A comparative analysis of current methods | 2015 | *Moreno-Gutiérrez et al. (2015)* | Eq. 1 | Strait of Gibraltar / Europe | 2 |
| The Estimation of Container Ship Emissions at Berth in Taiwan | 2015 | *Cullinane et al. (2015)* | Eq. 2 | Berth in Taiwan / Asia | 2 & 3 |
| An AIS-based high-resolution ship emission inventory and its uncertainty in Pearl River Delta region, China | 2016 | *Li et al. (2016)* | Eq. 1 and 2 | Pearl river delta region, China / Asia | 2 |
| Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution | 2017 | *Johansson et al. (2017)* | STEAM3 | Worldwide | 1 |
| High-spatiotemporal-resolution ship emission inventory of China based on AIS data in 2014 | 2017 | *Chen et al. (2017)* | Eq. 2 | China / Asia | 2 |
| Contribution of ship emissions to the concentration of PM2.5 A comprehensive study using AIS data and WRF-Chem model in Bohai Rim Region, China | 2018 | *Chen et al. (2018)* | Eq. 2 | Bohai Rim region, China / Asia | 2 |
| Estimation and assessment of shipping emissions in the region of Ambarli Port, Turkey | 2009 | *Deniz and Kilic (2009)* | Eq. 4 | Ambarli Port, Turkey / Europe | 3 |
| Air quality impact assessment of at-berth ship emissions: Case-study for the project of a new freight port | 2010 | *Lonati et al. (2010)* | Eq. 4 | Mediterranean Sea / Europe | 3 |
| Ship emissions and their externalities for the port of Piraeus e Greece | 2010 | *Tzannatos (2010)* | Eq. 2 | port of Piraeus e Greece / Europe | 3 |
| Estimating GHG emissions of marine ports: The case of Barcelona | 2011 | *Villalba and Gemechu (2011)* | Eq. 2 | Barcelona / Europe | 3 |
| Estimating transportation-related greenhouse gas emissions in the Port of Busan | 2011 | *Shin and Cheong (2011)* | Eq. 3 | Port of Busan / Asia | 3 |
| Estimating the environmental costs of port related emissions: The case of Kaohsiung | 2012 | *Berechman and Tseng (2012)* | Eq. 2 | Kaohsiung, Taiwan / Asia | 3 |
| An Investigation on the Effects of Ship Sourced Emissions in Izmir Port, Turkey | 2013 | *SaracoLlu et al. (2013)* | Eq. 2 | Izmir Port, Turkey / Europe | 3 |
| Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon | 2013 | *Chang et al. (2013)* | Eq. 4 | Korea's Port of Incheon / Asia | 3 |
| Current and future emission estimates of exhaust gases and particles from shipping at the largest port in Korea | 2014 | *Song and Shong (2014)* | Eq. 2 | port in Korea / Asia | 3 |
| Manoeuvring and hotelling external costs: enough for alternative energy sources? | 2014 | *Sanabra et al. (2013)* | Eq. 2 | Spanish port / Europe | 3 |
| Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port | 2014 | *Song (2014)* | Eq. 2 | Shanghai / Asia | 3 |
| Sulfur dioxide emission estimates from merchant vessels in a Port area and related control strategies | 2014 | *Liu et al. (2014)* | Eq. 2 and 3 | Port of Kaohsiung, Taiwan / Asia | 3 |
| Evaluating the social cost of cruise ships air emissions in major ports of Greece | 2015 | *Maragkogianni and Papaefthimiou (2015)* | Eq. 2 | ports of Greece / Asia | 3 |
| Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data e An Australian case study | 2015 | *Goldsworthy and Goldsworthy (2015)* | Eq. 2 | Australian coast and Australian ports / Oceania | 3 |

| | | | | | |
|---|---|---|---|---|---|
| Port-city exhaust emission model: an application to cruise and ferry operations in Las Palmas Port. | 2015 | *Tichavska and Tovar (2015)* | STEAM | Las Palmas port / Africa | 3 |
| Estimating ship emissions based on AIS data for port of Tianjin, China | 2016 | *Chen et al. (2016)* | Eq. 2 | port of Tianjin, China / Asia | 3 |
| Effects of slow steaming strategies on a ship fleet | 2017 | *Cepeda et al. (2017)* | Eq. 1 | Bulk carrier ship fleet, route Brazil to China | 1 |
| Air emissions from ships in port: Does regulation make a difference? | 2017 | *Tichavska et al. (2017)* | STEAM | Las Palmas, St. Petersburg, and Hong Kong /Africa, Europe and Asia | 3 |
| Estimation and spatio-temporal analysis of ship exhaust emission in a port area | 2017 | *Huang et al. (2017)* | Eq. 2 and 3 | Ningbo-Zhoushan port in China / Asia | 3 |
| Ship emission inventory and its impact on the PM2.5 air pollution in Qingdao Port, North China | 2017 | *Chen et al. (2017)* | Eq. 2 | Qingdao Port, North China / Asia | 3 |

Table I helps us to identify the state of the art methodology among the 36 studies reviewed. Eq.(2) appeared to be the most used, see Fig.1. Later in this paper, Eq.(2) will be improved in order to assess the emissions.

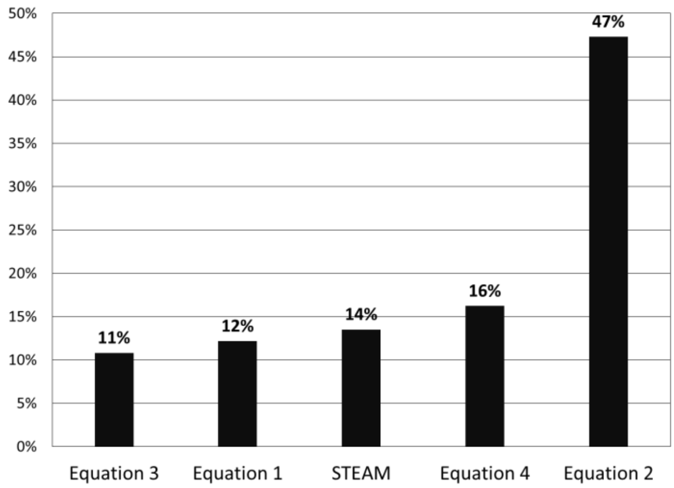



Fig.1: Methodologies used to inventory the ship emissions based on Table I

Despite the existence of several studies about the quantification of the impact of contaminants on the environment of the Rio de Janeiro Bay there still a lack of studying the emissions of the marine traffic in the region. Table II identifies several papers on environmental factors including information about year of publication, the authors involved. Most of the studies relates to water pollution and concentration of pollutants in the Bay. Only one study deals with supply boats emissions trying to identify what is the proportion of the emissions related to ships in the data measured by the air pollution meters of the State Institute Environment (INEA).

In this paper, detailed characteristics of the emissions over Rio de Janeiro are reported based on AIS data. The estimations show the quantity of tonnes of $CO_2$, $SO_2$, $NO_X$, $PM_{10}$, and $PM_{2.5}$ emitted and dispersed around the Rio de Janeiro bay. This study complies with the objective of inventorying emissions around Rio de Janeiro (Ganabara Bay including port), following the recommendations of the IMO to lower emissions until 2020. If emissions are not estimated, we could not reach the goal of reducing them.

Table II: Summary of the environmental factors studied in the surrounding of Guanabara Bay

| Title of the study | Year | Reference | Factors studied |
|---|---|---|---|
| Spatial variation, speciation and sedimentary records of mercury in the Guanabara Bay (Rio de Janeiro, Brazil) | 2012 | *Covelli et al. (2012)* | Hg accumulation in bottom sediments on the northwestern side of the Bay. |
| Stormwater impact in Guanabara Bay (Rio de Janeiro): Evidences of seasonal variability in the dynamic of the sediment heavy metals | 2013 | *Fonseca et al. (2013)* | Concentration and fractionation of the heavy metals within the sediments of the bay. |
| Emissões de $NO_X$ e $SO_2$ por embarcações do tipo supply boat fundeadas no Porto do Rio de Janeiro e o impacto na qualidade do ar | 2015 | *Machado de Paula (2015)* | $NO_X$ and $SO_2$ emissions from supply boats anchored in Guanabara Bay |
| Comparações entre medições em tempo real da $pCO_2$ aquática com estimativas indiretas em dois estuários tropicais contrastantes: o estuário eutrofizado da Baía de Guanabara (RJ) 2016 | 2016 | *Cotovicz et al. (2016)* | Concentration of water $pCO_2$, with calculations based on pH and total alkalinity (TA) in two contrasting Brazilian estuaries: GB and the São Francisco River Estuary (Alagoas). |
| Spatio-temporal variability of methane ($CH_4$) concentrations and diffusive fluxes from a tropical coastal embayment surrounded by a large urban area (Guanabara Bay, Rio de Janeiro, Brazil) | 2016 | *Cotovicz et al. (2016)* | Urban pollution as CH4 to the coastal waters |
| Ecological risks of trace metals in Guanabara Bay, Rio de Janeiro, Brazil: An index analysis approach | 2016 | *De Carvalho Aguiar et al. (2016)* | Contamination of Guanabara Bay through the selection of different environmental indices as metal contamination and also investigate potential biological hazard. |
| An environmental overview of Guanabara Bay, Rio de Janeiro | 2016 | *Soares-Gomes et al. (2016)* | Geomorphology, climatology, hydrology, geography and biodiversity aspects |
| Microplastic pollution of the beaches of Guanabara Bay, Southeast | 2016 | *De Carvalho and Neto (2016)* | Composition and distribution of micro-plastics and small plastic fragments on the beaches of Guanabara Bay |
| Environmental change in Guanabara Bay, SE Brazil, based in microfaunal, pollen and geochemical proxies in sedimentary cores | 2017 | *Neto et al. (2017)* | Sediment transport of pollution (municipal wastewater, deforestation, urban runoff and industrial effluents) |
| The urban heat island in Rio de Janeiro, Brazil, in the last 30 years using remote sensing data | 2018 | *Peres et al. (2018)* | Analysis of land-surface temperature of "vegetation" land-use class in Metropolitan Area of Rio de Janeiro |
| Determination of water quality, toxicity and estrogenic activity in a nearshore marine environment in Rio de Janeiro, Southeastern Brazil | 2018 | *Do Nascimento et al. (2018)* | It evaluates the estrogenic potential of water sampled from different depths and from areas with differential contamination levels throughout Jurujuba Sound |

## 2. Methodology and data

### 2.1. Study area

The Guanabara Bay is an oceanic bay, located on the Southeast Brazil in the state of Rio de Janeiro between 2240S and 2300S latitude and between 04300W and 04318W longitude. The Bay is known as the second largest bay in area in Brazil (after the All Saints' bay). It has an area of approximately 384 $km^2$, including islands. On its western shore lies the city of Rio de Janeiro and fifteen other municipalities. The populated region around the studied area is composed by the following 16 municipalities, Fig.2. It was representing 12 million people in 2017 based on Brazilian Institute of Geography and Statistics data. The main port area in the Ganabara Bay is the Port of Rio de Janeiro, located in downtown of the homonymous city of Rio de Janeiro at 2345 S and 4445 W, Fig.3. International shipping associated with the development of the country and petroleum industry increased the marine traffic through the Bay, which poses significant risks to the biodiversity and the marine environment, the livelihood of the coastal communities, and the fishing and tourism industries. Five types of facilities are distributed throughout the bay that are heart of industry and mass transit of people.

These places are: dry cargo terminal, passenger terminals, petroleum terminals, shipyards, navy facilities and yacht clubs. This study examines the distribution of the emissions produced by the marine traffic that may potentially affect up to 12 million people.

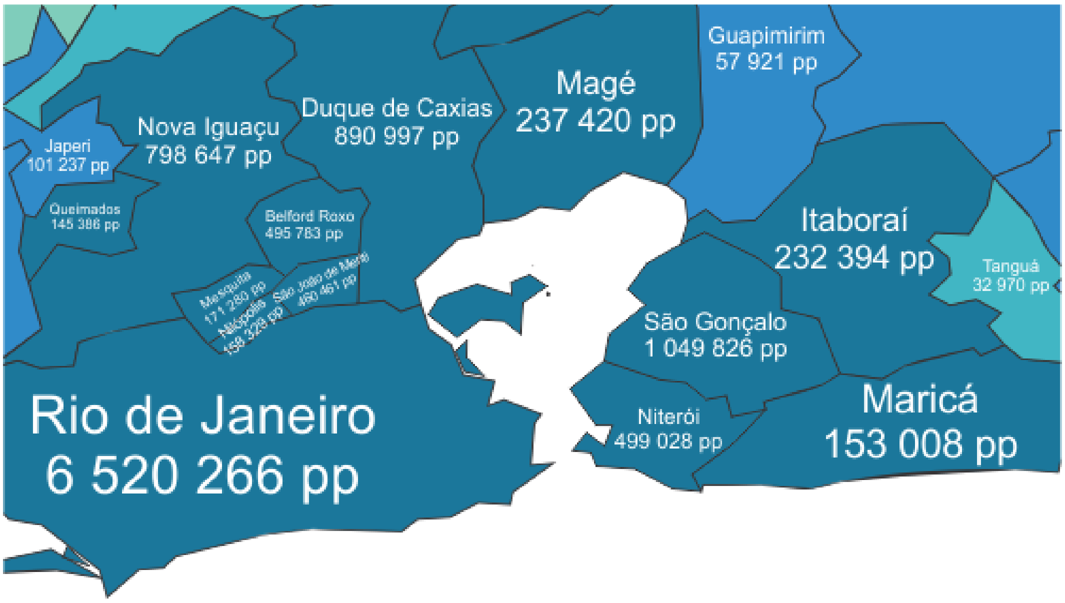



Fig.2: Map of the regions surrounding the bay with total of habitant in 2017 based on Brazilian Institute of Geography and Statistics data

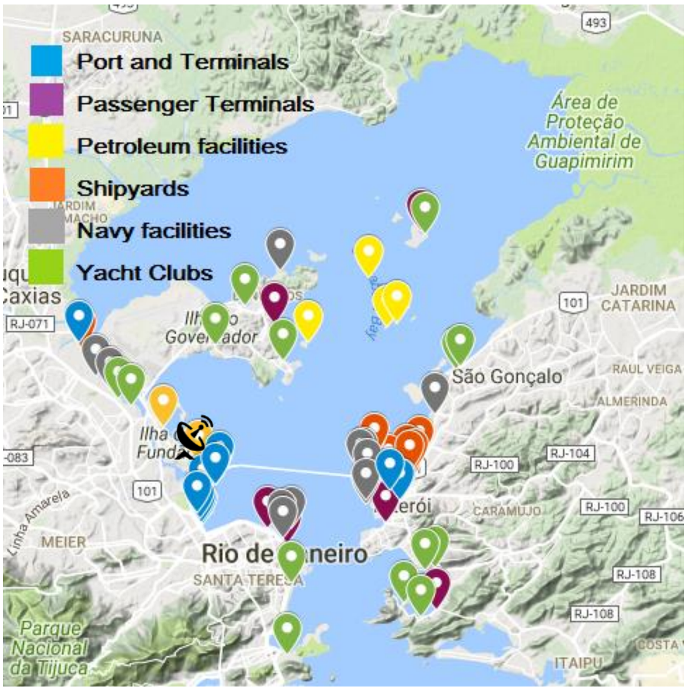



Fig.3: View of Guanabara Bay included six types of industrial/commercial facilities in the area

### 2.2. Automatic Identification System (AIS) data and ship information data

The Automatic Identification System (AIS) is a mandatory collision avoidance system required to be installed on ships by the International Maritime Organization (IMO) and the Maritime Safety Administration of several countries. The AIS system makes it possible to locate the great majority of vessels throughout the world. International voyaging ships with a Gross Tonnage (GT) of 300 or more, passenger ships of all sizes, domestic vessels with a GT of 200 or more traveling in coastal waters, and inland ships with a GT of 100 or more, are all required to be equipped with AIS. Special purpose vessels such as military ships, fishery ships, sports ships, and public service ships are exceptions, *Chen et al. (2016), IMO (2003)*.

There are in fact two type of AIS, *Kerbiriou et al. (2017)*:

1. Class A: transponders are mandatory on board merchant ships exceeding 300 tonnages and all passenger ships meeting SOLAS standards (merchant navy, ferries, etc.).
2. Class B: transponders concern small ships that are not required to comply with SOLAS conventions (recreational vessels, fishing vessels of less than 15 meters, etc.), to enable them to adapt voluntarily to the AIS system.

In this study, both AIS-A and AIS-B has been considered.

The objectives of IMO implementing the AIS system are to enhance the safety and efficiency of navigation, safety of life at sea, and protection of maritime environment. AIS facilitates communication between vessels and assist vessel traffic control functions in congested ports, locks and waterways, *Kerbiriou et al. (2017)*. The reported AIS data can be divided into static, dynamic, and voyage-related data categories: static information includes ship name, ship type, length, breadth, etc.; dynamic data includes ship speed over ground, navigational status (operating mode), heading, rate of turn, position, etc.; and voyage-related data includes current draught, description of cargo, and destination, *IMO (2003)*. Besides ship information reported by AIS, detailed data for ship type, ship size, date of construction, design speed, gross tonnage and power of the engines can be obtained from others databases such as Marine Traffic or IHS.

This work is based on data collected by the AIS base station called UFRJ-COPPE for January and February 2018. The hardware consist in one omnidirectional Sirio GP6E antenna of 2x5/8λ (162 Mhz), one AIS receiver COMAR SLR350N and one Raspberry Pi 3 to provide Ethernet connectivity and to host a NMEA multiplexer server. A NMEA message decoder as well as a Microsoft SQL server compose the data warehouse configuration. The main table in the database contains 196 different fields extracted from the messages. The average range of the configuration is 11 NM with a maximum of 74.5 NM. The average AIS messages quantity is about 395 per minute. The location of the system is plotted in Fig.3**Error! Reference source not found.**.

Fig.4 shows the distribution of the type of ships of the 317 vessels recorded during the period of the study (January and February 2018). The vessels that presented less than 500 AIS position reports in the DB has been disregarded in this study.

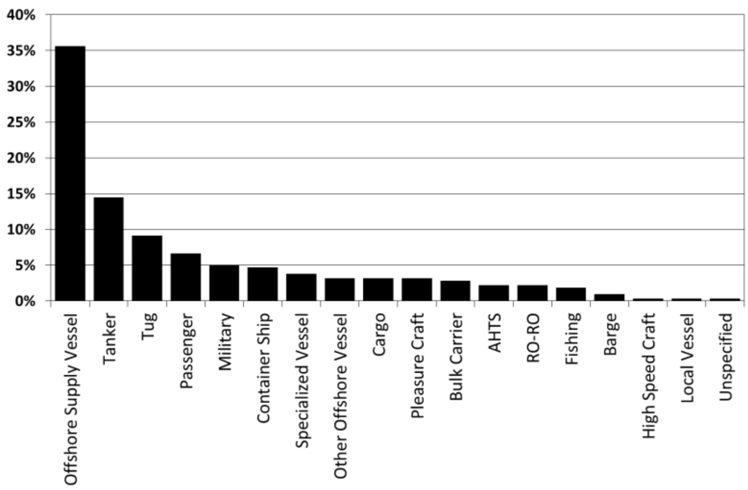



Fig.4: Distribution of the type of ships

### 2.3. Estimation of ship emissions

The methodology of ship emissions assessment has been adapted from Eq.(2). The $CO_2$, $SO_2$, $NO_X$, $PM_{10}$, and $PM_{2.5}$ emissions has been calculated between two report positions of a vessel using **Error! Reference source not found.** proposed by *Entec (2002), Goldsworthy and Goldsworthy (2015)*. This formulation depends mainly of the installed power of the ship engines, type of the fuel used as well as of the load factor of the engine. However, these data are not provided by the AIS.

$$\boldsymbol{E_{i,j,k,l} = P_j \times LF_{j,l} \times T_{j,k.l} \times EF_{i,j,k} / 10^6} \quad (5)$$

$$\boldsymbol{LF_{j,l}} = (\boldsymbol{AS/MS})^{\boldsymbol{3}} \quad (6)$$

Where,

| | |
|---|---|
| $E_{i,j,k,l}$ | Total emission of pollute $\boldsymbol{i}$ from engine $\boldsymbol{j}$ using fuel type $\boldsymbol{k}$ during operation mode $\boldsymbol{l}$ (tons); |
| $\boldsymbol{P_j}$ | Installed power for engines j (kW); |
| $LF_{j,l}$ | Load factor for engine j during operation mode l (%); |
| $\boldsymbol{T_{j,k.l}}$ | Operating time for engine type j, using fuel type k during operation mode l (h); |
| $EF_{i,j,k}$ | Emission factor for pollute $\boldsymbol{i}$ from engine $\boldsymbol{j}$ using fuel type $\boldsymbol{k}$ (g/kWh); |
| $\boldsymbol{AS}$ | Actual Speed (knots); |
| $\boldsymbol{MS}$ | Maximum Speed (knots). |

The following steps has been applied to obtain the installed power of the main engines in kW:

1. Preferentially use the real data of the propulsion system when available (from Marine Traffic)
2. Else, use the regressions presented in Table III to assess the installed main engines power in kilowatts. These regression has been established analysing a sample of the world fleet database considering 11127 ships.

Table III: Regressions to obtain the information about rated power of main engine by ship type

| Ship type | Quantity | Mean of power | STDV of power | Engine type | Regression equation | $R^2$ |
|---|---|---|---|---|---|---|
| AHTS | 3174 | 5581,18 | 3525,54 | MSD | kW = 2,4099*GT + 1416,8 | 0,7358 |
| Tanker | 1108 | 2613,88 | 3218,28 | SSD | kW = 12,753*GT^0,6404 | 0,9099 |
| Container | 557 | 25329,86 | 20001,74 | SSD | kW = 3,0051*GT^0,8615 | 0,9424 |
| Bulker | 404 | 7987,68 | 4975,47 | SSD | kW = 23,444*GT^0,5634 | 0,9474 |
| General Cargo | 1211 | 2381,23 | 2050,77 | SSD | kW = 0,555*GT + 282,8 | 0,8934 |
| Fishing | 1985 | 931,34 | 814,07 | MSD | kW = -4E-05*GT^2 + 1,4125*GT +358,69 | 0,742 |
| OSV | 1531 | 5174,06 | 2105,61 | MSD | kW = 15,357*GT^0,7322 | 0,7286 |
| Cruise | 26 | 33430,90 | 28987,76 | MSD | kW = 0,5885*GT^1,0176 | 0,9826 |
| Pleasure Craft | 33 | 1634,19 | 1966,94 | HSD | kW = 1,7562*GT + 472,95 | 0,725 |
| Vehicle Carrier | 67 | 8938,13 | 7040,49 | SSD | kW = 15,902*GT^0,665 | 0,8413 |
| Tug | 946 | 2121,11 | 970,89 | MSD | kW = -0,008*GT^2 + 11,312*GT - 84,006 | 0,5017 |
| Diving Vessel | 85 | 5183,33 | 4234,57 | MSD | kW = 0,3742*GT^2,1622 | 0,8266 |

The emissions factors used in this study are taken from *Fan et al. (2016)* considering the machine type as ME and the oil type as RO for all the ships. For each engine, the corresponding emission factors were applied, as described in Table IV. The auxiliary engines used for generating energy on-board has been disregarded in the present study due to the difficulty to obtain the correct installed power of this type of equipment.

Table IV: Emission factors ($CO_2$, $SO_2$ and $NO_X$, $PM_{10}$, and $PM_{2.5}$) for pollute and fuel type for each engine type (g/kWh), *Chen et al. (2016), Fan et al. (2016)*

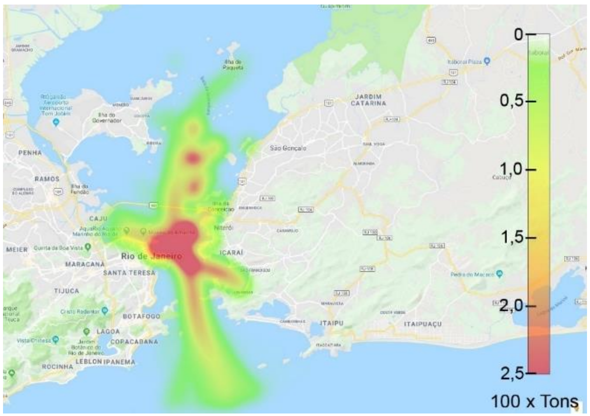
| Machine type | Engine Type | Oil Type | $CO_2$ | $SO_2$ | $NO_X$ | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|---|---|
| ME | Slow Speed Diesel (SSD) | Residual Oil (RO) | 622 | 10.30 | 18.10 | 1.378 | 1.22 |
| ME | Medium Speed Diesel (MSD) | Residual Oil (RO) | 686 | 11.31 | 14.00 | 1.193 | 1.22 |
| ME | High Speed Diesel (HSD) | Residual Oil (RO) | 686 | 11.31 | 12.7 | 0.65 | 0.50 |

## 3. Results

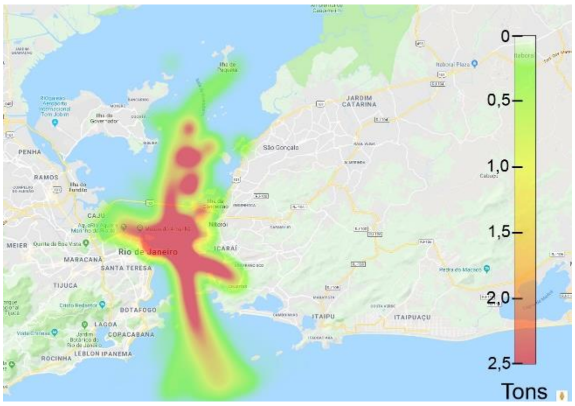
Total estimated emissions from ships for January and February 2018 as well as an estimation of the annual average are presented in Table V. The $CO_2$ emissions are the most important with over than 40000 t per year followed by $NO_x$ and $SO_2$ emissions. The AIS data allowed plotting a high-resolution geographical characterization of emissions.

Table V: Total of emission due to marine traffic in Rio de Janeiro

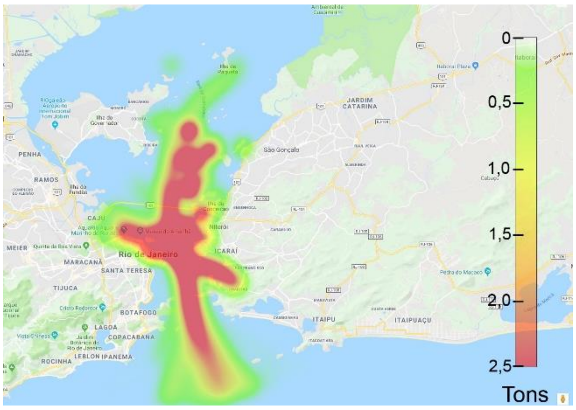
| | $CO_2$ | $SO_2$ | $NO_X$ | $PM_{10}$ | $PM_{2.5}$ |
|---|---|---|---|---|---|
| | [Tons] | [Tons] | [Tons] | [Tons] | [Tons] |
| Jan. and Feb. 2018 | 6701.4 | 111.0 | 147.9 | 12.9 | 12.8 |
| Annual average | 40208.4 | 666.0 | 887.4 | 77.4 | 76.8 |



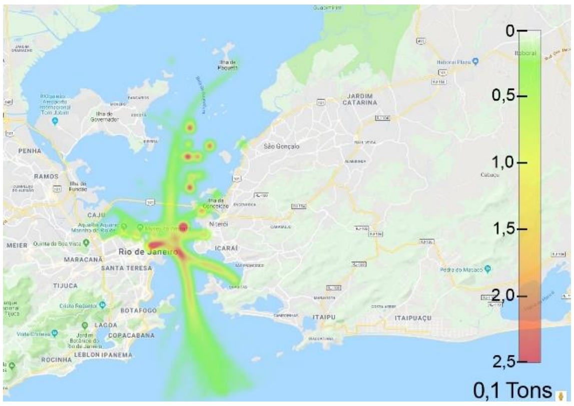

(a) $CO_2$ emissions



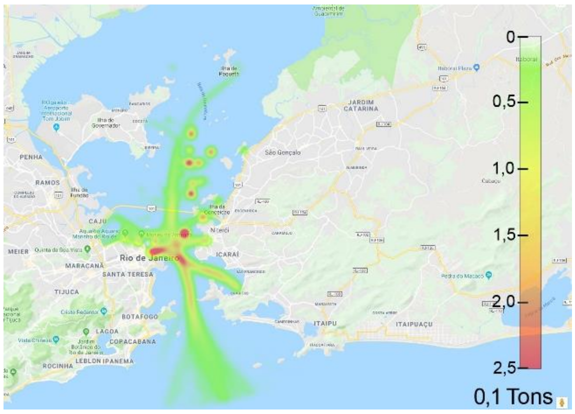

(b) $SO_2$ emissions




(c) $NO_X$ emissions




(d) $PM_{10}$ emissions




(e) $PM_{2.5}$ emissions

Fig.5: Distribution of emissions in tons per year around Rio de Janeiro (Guanabara Bay)

The heat maps of the quantitative assessment of the emissions are illustrated in Fig.5. These maps have been constructed using Google maps API through solution provided by Raffael Vogler in (www.joyofdata.de). The API calculates the heat map based in the contribution of each point in 50 pixels of distance. The map's maximum intensity is fixed at 2.5 t and is represented by the red color. Color gradient follow the default order: light green, yellow, orange and red, representing roughly 25%, 50%, 75% and 100% or more of the maximum intensity. The peak of the emissions is observed at the south part of the bridge between Rio de Janeiro downtown center and Niteroi municipalities.

The assessment of the emission impacts on the population of the surrounding municipalities is out of the scope of this study. To be able to reach this objective, other important source of emissions should be considered as well as other important factors such as dispersions and dilution.

## 4. Conclusions and recommendations

The Rio de Janeiro Guanabara Bay, one of the busiest ports of Brazil, has a great environmental and socio-economic importance for the region of the study. Its current state of environmental degradation including by GHG emissions poses risks to the human populations of its surroundings, who use its waters for pleasure, transportation, or for their livelihood. This study focus the assessment of the emissions due to marine traffic base on 2 months AIS data (January and February 2018). The major findings of this study, which is the first ship emission inventory for this zone, may be summarized as follows: Total estimated emissions from ships for January and February 2018 are 6701.4 tons of $CO_2$, 111.0 tons of $SO_2$, 147.9 tons of $NO_X$, 12.9 tons of $PM_{10}$ and 12.8 tons $PM_{2.5}$. Continuously storing AIS data will allows us in the near future to better understand the distribution of ship emissions in the Rio the Janeiro Bay. However, a special attention should be payed to the construction of consistent databases about the ship engines installed power for both main propulsion and auxiliary power units.


## Acknowledgements

This research was partially supported by the Coordination for the Improvement of Higher Education Personnel (CAPES).


## References


BERECHMAN, J.; TSENG, P.H. (2012), *Estimating the environmental costs of port related emissions: The case of Kaohsiung*, Transportation Research Part D, 17, pp.35-38

CEPEDA, M.; ASSIS, L.; MARUJO, L.; CAPRACE, J.D. (2017), *Effects of slow steaming strategies on a ship fleet*, Marine Systems & Ocean Technology 12/3, pp.178-186

CHANG, Y.T.; SONG, Y.; ROH, Y. (2013), *Assessing greenhouse gas emissions from port vessel operations at the Port of Incheon*, Transportation Research Part D 25, pp.1-4

CHEN, D.; WANG, X.; LI, Y.; LANG, J.; ZHOU, Y.; GUO, X.; ZHAO, Y. (2017), *High-spatiotemporal-resolution ship emission inventory of China based on AIS data in 2014*, Science of the Total Environment 609, pp.776-787

CHEN, D.; WANG, X.; NELSON, P.; LI, Y.; ZHAO, N.; ZHAO, Y.; GUO, X. (2017), *Ship emission inventory and its impact on the PM 2.5 air pollution in Qingdao Port, North China*. Atmospheric Environment 166, pp.351-361

CHEN, D.; ZHAO, N.; LANG, J.; ZHOU, Y.; WANG, X.; LI, Y.; GUO, X. (2018), *Contribution of ship emissions to the concentration of PM2.5: A comprehensive study using AIS data andWRF/ Chemmodel in Bohai Rim Region, China*, Science of the Total Environment, pp.1476-1486

CHEN, D.; ZHAO, Y.; NELSON, P.; LI, Y.; WANG, X.; ZHOU, Y.; GUO, X. (2016), *Estimating ship* *emissions based on AIS data for port of Tianjin, China*, Atmospheric Environment 145, pp.10-18

COELLO, J.; WILLIAMS, I.; HUDSON, D.; KEMP, S. (2015), *An AIS-based approach to calculate atmospheric emissions from the UK fishing fleet*, Atmospheric Environment 114, pp.1-7

COOPER, D. (2003), *Exhaust emissions from ships at berth*, Atm. Environment 37, pp.3817-3830

COOPER, D.; GUSTAFSSON, T. (2004), *Methodology for calculating emissions from ships: 1. Update of emission factors*, Report Series Swedish Methodology for Environmental Data 4

COTOVICZ, L.; KNOPPERS, B.; BRANDINI, N.; POIRIER, D.; COSTA SANTOS, S.; ABRIL, G. (2016), *Spatio-temporal variability of me-thane (CH4) concentrations and diffusive fluxes from a tropical coastal embayment surrounded by a large urban area (Guanabara Bay, Rio de Janeiro, Brazil)*, Limnology and Oceanography, pp.7-15

COTOVICZ, L.; LIBARDONI, B.; BRANDINI, N.; KNOPPERS, B.; ABRIL, G. (2016), *Comparações entre medições em tempo real da pCO2 aquática com estimativas indiretas em dois estuários tropicais contrastantes: o estuário eutrofizado da Baía de Guanabara (RJ) e o Estuario oligotrófico do Rio Sao Francisco*, Quimica Nova 15, pp.1-9

COVELLI, S.; PROTOPSALTI, I.; ACQUAVITA, A.; SPERLE, M.; BONARDI, M.; EMILI, A. (2012), *Spatial variation, speciation and sedimentary records of mercury*, Continental Shelf Research 35, pp.29-42

CULLINANE, K.; TSENG, P.-H.; WILMSMEIER, G. (2015), *The estimation of container ship emissions at berth*, Int. J. Sustainable Transportation 10/5, pp.466-474

DALSØREN, S.B.; EIDE, M.S.; ENDRESEN, Ø.; MJELDE, A. (2009), *Update on emissions and environmental impacts from the international fleet of ships. The contribution from major ship types and ports*, Atmospheric Chemistry and Physics 9, pp.2171-2194

DE CARVALHO AGUIAR, V.; NUNES DE LIMA, M.; COUTINHO ABUCHACRA, R.; FERREIRA FALHEIRO ABUCHACRA, P.; BAPTISTA NETO, J.; VARGAS BORGES, H.; CALÔR DE OLI-VEIRA, V. (2016), *Ecological risks of trace metals in Guanabara Bay, Rio de Janeiro, Brazil: An index analysis approach*, Ecotoxicology and Environmental Safety 133, pp.306-315

DE CARVALHO, D.; NETO, J.B. (2016), *Microplastic pollution of the beaches of Guanabara Bay, Southeast*, Ocean & Coastal Management 128, pp.10-17

DE MENDONÇA OCHS, S.; DE ALMEIDA FURTADO, L.; DUARTE PEREIRA NETTO, A. (2015), *Evaluation of the concentrations and distribution of carbonyl compounds in selected areas of a Brazilian bus terminal*, Environmental Science and Pollution Research, pp.9413-9423

DENIZ, C.; KILIC, A. (2009), *Estimation and assessment of shipping emissions in the region of Ambarli Port, Turkey*, Environmental Progress & Sustainable Energy 29/1, pp.107-115

DENIZ, C.; KILIC, A.; CIVKAROGLU, G. (2010), *Estimation of shipping emissions in Candarli Gulf, Turkey*, Environ Monit. Assess. 171, pp.219-228

DO NASCIMENTO, M.L.; SANTOS, A.D.; FELIX, L.; GOMES, G.; DE OLIVEIRA E SA, M.; DA CUNHA, D.L.; BILA, D.M. (2018), *Determination of water quality, toxicity and estrogenic activity in a nearshore marine environment in Rio de Janeiro, Southeastern Brazil*, Ecotoxicology and Environmental Safety 149, pp.197-202

ENTEC (2002), *Quantification of emissions from ships associated with ship movements between ports* *in the European Community*, Final Report, European Commission, Entec UK Ltd.

FAN, Q.; ZHANG, Y.; MA, W.; MA, H.; FENG, J.; YU, Q.; CHEN, L. (2016), *Spatial and Seasonal Dynamics of Ship Emissions over the Yangtze River Delta and East China Sea and Their Potential Environmental Influence*, Environ. Sci. Technol., pp.1322-1329

FONSECA, E.; BAPTISTA NETO, J.; SILVA, C.; McALISTER, J.; SMITH, B.; FERNANDEZ, M. (2013), *Stormwater impact in Guanabara Bay (Rio de Janeiro): Evidences of seasonal variability in the dynamic of the sediment heavy metals*, Estuarine, Coastal and Shelf Science, pp.161-168

GOLDSWORTHY, B. (2017), *Spatial and temporal allocation of ship exhaust emissions in Australian coastal waters using AIS data: Analysis and treatment of data gaps*, Atmospheric Environment 163, pp.77-86

GOLDSWORTHY, L.; GOLDSWORTHY, B. (2015), *Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data e An Australian case study*, Environmental Modelling & Software 63, pp.45-60

HEITMANN, N.; PETERSON, S. (2014), *The potential contribution of the shipping sector to an efficient reduction of global carbon dioxide emissions*, Environmental Science & Policy 42, pp.56-66

HOWITT, O.; REVOL, V.; SMITH, I.; RODGER, C. (2010), *Carbon emissions from international cruise ship passengers' travel to and from New Zealand*, Energy Policy 8/5, pp.2552-2560

HUANG, L.; WENG, Y.; GENG, X.; ZHOU, C.; XIAO, C.; ZHANG, F. (2017), *Estimation and spatio-temporal analysis of ship exhaust emission in a port area*, Ocean Engineering 140, pp.401-411

IBM (2014), *Big data and analytics in travel and transportation*, IBM Big Data and Analytics, pp.1-12

IMO (2003), *Guidelines for the installation of a shipborne automatic identification system (AIS)*, Int. Maritime Organization, London

JALKANEN, J.P.; BRINK, A.; KALLI, J.; PETTERSSON, H.; KUKKONEN, J.; STIPA, T. (2009), *A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area*, Atmospheric Chemistry and Physics 9, pp.9209-9223

JALKANEN, J.P.; JOHANSSON, L.; KUKKONEN, J. (2013), *A comprehensive inventory of the ship traffic exhaust emissions in the Baltic Sea from 2006 to 2009*, Ambio 43, pp.311-324

JOHANSSON, L. (2011), *Emission estimation of marine traffic using vessel characteristics and AIS-data*, Aalto University

JOHANSSON, L.; JALKANEN, J.P.; KUKKONEN, J. (2017), *Global assessment of shipping emissions in 2015 on a high spatial and temporal resolution,* Atmospheric Environment 167, pp.403-415

KALLI, J.; JALKANEN, J.P.; JOHANSSON, L.; REPKA, S. (2013), *Atmospheric emissions of European SECA shipping: long-term projections*, WMU J. Maritime Affairs 12, pp.129-145

KERBIRIOU, R.; LEVEQUE, L.; RAJABI, A.; SERRY, A. (2017), *The Automatic Identification System (AIS) as a data source for study maritime traffic*, 7th Int. Mar. Science Conf., Solin, pp.1-18

KEUKEN, M.; MOERMAN, M.; JONKERS, J.; HULSKOTTE, J.; GON, H.D.v.d.; HOEK, G.; SOKHI, R. (2014), *Impact of inland shipping emissions on elemental carbon concentrations near waterways in The Netherlands*, Atmospheric Environment 95, pp.1-9

KILIÇ, A.; DENIZ, C. (2010), *Inventory of Shipping Emissions in Izmit Gulf, Turkey*, Environmental Progress & Sustainable Energy 29/2, pp.221-232

LI, C.; YUAN, Z.; OU, J.; FAN, X.; YE, S.; XIAO, T.; ZHENG, J. (2016), *An AIS-based high-resolution ship emission inventory and its uncertainty*, Science of the Total Environment 573, pp.1-10

LINDSTAD, H.; SANDAAS, I.; STRØMMAN, A. (2015), *Assessment of cost as a function of abatement options in maritime emission control areas*, Transportation Research Part D 38, pp.41-48

LIU, T.K.; SHEU, H.Y.; TSAI, J.Y. (2014), Sulfur dioxide emission estimates from merchant vessels in a port area and related control strategy, Aerosol and Air Quality Research 14, pp.413-421

LONATI, G.; CERNUSCHI, S.; SIDI, S. (2010), *Air quality impact assessment of at-berth ship emissions: Case-study for the project of a new freight port*, Science of the Total Environ. 409, pp.192-200

MACHADO DE PAULA, R. (2015), *Emissões de NOx e SO2 por embarcações do tipo supply boat fundeadas no Porto do Rio de Janeiro e o impacto na qualidade do ar*, Universidade Federal do Rio de Janeiro, Escola Politécnica & Escola de Química, Rio de Janeiro: Programa de Engenharia Ambiental

MARAGKOGIANNI, A.; PAPAEFTHIMIOU, S. (2015), *Evaluating the social cost of cruise ships air emissions in major ports of Greece*, Transportation Research Part D 36, pp.10-17

McARTHUR, D.; OSLAND, L. (2013), *Ships in a city harbour: An economic valuation of atmospheric emissions*, Transportation Research Part D 21, pp.47-52

MILOSLAVSKAYA, N.; TOLSTOY, A. (2016), *Big Data, Fast Data and Data Lake Concepts*. Procedia Computer Science 88, pp.300-305

MORENO-GUTIÉRREZ, J.; CALDERAY, F.; SABORIDO, N.; BOILE, M.; VALERO, R.; DURÁN-GRADOS, V. (2015), *Methodologies for estimating shipping emissions and energy consumption: A comparative analysis of current methods*, Energy 86, pp.603-616

NETO, J.A.; BARRETO, C.F.; VILELA, C.G.; DA FONSECA, E.M.; MELO, G.V.; BARTH, O.M. (2017), *Environmental change in Guanabara Bay, SE Brazil, based in microfaunal, pollen and geochemical proxies in sedimentary cores*, Ocean & Coastal Management 143, pp.4-15

NG, S.; LOH, C.; LIN, C.; BOOTH, V.; CHAN, J.; YIP, A.; LAU, A. (2013), *Policy change driven by an AIS-assisted marine emission inventory in Hong Kong and the Pearl River Delta*, Atmospheric Environment 76, pp.102-112

NUNES, R.; ALVIM-FERRAZ, M.; MARTINS, F.; SOUZA, S. (2017), *The activity-based methodology to assess ship emissions - A review*, Environmental Pollution 231, pp.87-103

PERES, L.D.; DE LUCENA, A.; ROTUNNO FILHO, O.C.; FRANÇA, J.d. (2018), *The urban heat island in Rio de Janeiro, Brazil, in the last 30 years using remote sensing data*, Int. J. Appl. Earth Obs. Geoinformation 64, pp.104-116

PITANA, T.; KOBAYASHI, E.; WAKABAYASHI, N. (2010), *Estimation of exhaust emissions of marine traffic using AIS data*, IEEE OCEANS Conf, Sydney

SANABRA, M.; SANTAMARIA, J.; DE OSES, F. (2013), *Manoeuvring and hotelling external costs: enough for alternative energy sources?*, Maritime Policy & Management

SARAÇOLLU, H.; DENIZ, C.; KILIÇ, A. (2013), *An investigation on the effects of ship sourced* *emissions in Izmir Port, Turkey*, The Scientific World Journal, pp.1-8

SHIN, K.; CHEONG, J.P. (2011), *Estimating transportation-related greenhouse gas emissions in the Port of Busan, S. Korea*, Asian J. Atmospheric Environment 5/1, pp.41-46

SOARES-GOMES, A.; DA GAMA, B.; NETO, J. B.; FREIRE, D.; CORDEIRO, R.; MACHADO, W.; PEREIRA, R. (2016), *An environmental overview of Guanabara Bay, Rio de Janeiro*, Regional Studies in Marine Science 8, pp.319-330

SONG, S. (2014), *Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port*, Atmospheric Environment 82, pp.288-297

SONG, S.K.; SHONG, Z.H. (2014), *Current and future emission estimates of exhaust gases and particles from shipping at the largest port in Korea*, Env. Science & Poll. Research 21, pp.6612-6622

STYHRE, L.; WINNES, H.; BLACK, J.; LEE, J.; LE-GRIFFIN, H. (2017), *Greenhouse gas emissions from ships in ports – Case studies in four continents*, Transportation Research Part D 54, pp.212-224

TICHAVSKA, M.; TOVAR, B. (2015), *Port-city exhaust emission model - An application to cruise and ferry operations in Las Palmas Port*, Transportation Research Part A 78, pp.347-360

TICHAVSKA, M.; TOVAR, B.; GRITSENKO, D.; JOHANSSON, L.; JALKANEN, J. (2017), *Air emissions from ships in port: Does regulation make a difference?* Transport Policy

TZANNATOS, E. (2010), *Ship emissions and their externalities for the port of Piraeus, Greece*, Atmospheric Environment 44, pp.400-407

UNCTAD (2017), *Review of maritime transport 2017*, United Nations

VILLALBA, G.; GEMECHU, E. (2011), *Estimating GHG emissions of marine ports - the case of Barcelona*, Energy Policy 39, pp.1363-1368

WANG, K.; FU, X.; LUO, M. (2015), *Modeling the impacts of alternative emission trading schemes on international shipping*, Transportation Research Part A 77, pp.35–49

WESTERLUND, J.; HALLQUIST, M.; HALLQUIST, Å. (2015), *Characterization of fleet emissions from ships through multi-individual determination of size-resolved particle emissions in a coastal area*, Atmospheric Environment 112, pp.159-166

WINNES, H.; STYHRE, L.; FRIDELL, E. (2015), *Reducing GHG emissions from ships in port areas*, Research in Transportation Business & Management 17, pp.73-82

WINTHER, M.; CHRISTENSEN, J.; PLEJDRUP, M.; RAVN, E.; ERIKSSON, Ó.; KRISTENSEN, H. (2014), *Emission inventories for ships in the arctic based on satellite sampled AIS data*, Atmospheric Environment 91, pp.1-14

YAU, P.; LEE, S.; CORBETT, J.; WANG, C.; CHENG, Y.; HO, K. (2012), *Estimation of exhaust emission from ocean-going vessels in Hong Kong*, Science of the Total Environment 431, pp.299-306

YUAN, J.; NG, S.; SOU, W. (2016), *Uncertainty quantification of CO2 emission reduction for maritime shipping*, Energy Policy 88, pp.113-130

ZICARI, R. (2014), *Big Data: Challenges and Opportunities*, Big Data Computing, pp.103-130