# Validation of Satellite Based Observations of Ship Emissions -Coromandel Coast of INDIA

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**Abstract:** In recent years, shipping significantlycontributes to the world's anthropogenic emissions of sulphur, nitrogen and particulate matter. These species affect the global radiative forcing as well as local acidification, multiplication and human health, with a large impact oncomposition and chemistry of the marine boundary layer.Studies show that 70% of the global ship emissions occur within 400km from land and it is estimated that about 60,000 premature deaths per year are related to these emissions. The tightening of the environmental regulations has generated a need for cost - effective ship emissions monitoring. By January 2020 a 0.50% m/m limit in the sulphur content of the fuel will be introduced in the sea areas. The actual values of the ship emission are measured using some of the instruments by placing it onboard. New methods are emerging to verify bottom-up emission inventories and to estimate the emission level of shipping activity with satellite observations. Measurements from the GOME 2 (Global Ozone Monitoring Experiment-2) instrument onboard MetOp satellite have been analyzed for the shipping emissions along the coramandal coast of India. This route includes major port areas which has many main shipping lanes. The results here are to highlight the importance of ship emissions on the marine boundary layer and also to demonstrate the technology advancement of detecting emission using satellite data in an efficient way.

**Keywords:** Ship Emissions, Pollution, Remote Sensing, Satellite

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## 1. INTRODUCTION:

Emissions by ships significantly contribute to the total budget of anthropogenic emissions. The exhaust gas emissions from ships include CO2, NOx, SOx, CO, hydrocarbons, and particulate matter. Ship emissions are released into the marine boundary layer and change the chemical composition of the atmosphere and climate. Compared to other transport sectors the sulphur content of the fuel burned in marine diesel engines and the total amount of $SO_2$ emitted is high and results in a large amount of SOx and particulate matter emissions [1]. Estimated trend of the number of ships until 2050 derived from the global real GDP (gross domestic product) and world seaborne trade in tons, details and references see.

Over the past decades, the world’s ocean-going fleet and the total fuel consumption and emissions from international shipping have been substantially increased and a further increase is expected in the future as a result of economic growth and increased sea borne trade.

Currently ship emissions are one of the least regulated sources of anthropogenic emissions with a high reduction potential through technological improvements, alternative fuels and ship modifications. In order to protect the atmosphere, the International Maritime Organization (IMO), has given international limits forNOxemissions by ship engines in Annex VI of the Marine Pollution (MARPOL) Convention which entered into force in May 2005[2],[3].

National or regional regulations call for even more stringent NOx and SOx limits than those given by IMO. As a result, compliance with emission regulations through technological improvements will impact ship operators and the technology currently in use. Ship emissions not only change the chemical composition of the marine boundary layer, but it also contributes to air pollution in harbors. In addition, the particle emissions from ships also change the physical properties of low clouds and thereby contribute to climate change. The expected increase of emissions makes it important to examine the effects of global ship traffic on atmospheric composition and on the climate system and to predict its future impact. Data from satellites now allow constraining model calculations on the impact on chemical composition and climate change. Former studies for monitoring of ship emissions has been carried out by SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) instrument onboard the ENVISAT satellite provides the capability for global measurement of atmospheric NOX columns through observation of global backscatter[4]. However this was ended by May 2012. SCIAMACHY has been succeeded by

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GOME2 (Global Ozone Monitoring Experiment 2) satellite instrument in which global coverage can be achieved for every 1 day. The close relationship between tropospheric NOX and SOXcolumns and land surface $NO_x$ emissions has been previously demonstrated with SCIAMACHY observations. Here we used the GOME 2 higher resolution measurements to produce an improved $NO_x$ emission inventory.

## 2. INSTRUMENTS AND SOFTWARE'S USED:

### 2.1 Onboard observations

2.1.1 Air Quality Analyzer:

A set of monitoring instruments like air quality analyzer (respirable dust sampler) with gaseous sampling attachment and Testo 350 Maritime (Portable Emission Analyzer)has been installed on board for this study.The ambient air quality measurements are collected by placing the air quality analyzer instrument placed on board as shown in Fig.1.The amount of SOx and NOx emissions is studied using appropriate chemicals with the help of Gaseous Sampling Attachment. The air quality analysis process undertaken in this study will be implemented. Monitoring equipment could be installed on board every ship to transmit measurements on a regular basis. There are different possible configurations. The air sampler gives the measurement of NOx and SOx values along the ship track. When only fuel consumption is measured, emissions factors have to be applied for $NO_X$ and $SO_x$. The advantage is that a continuous measurement, anywhere and anytime, is possible. This is necessary for the implementation of an emissions trading system to be analyzing the application of on-board measurements to improve estimates of shipping emissions.

**Fig.1 Instrument used for Air quality measurements**

One of the issues during air sampling with the air quality analyzer is that it not only calculates the emission from ships but also the surrounding emissions i.e. (emission of tugs, trucks in port and nearby domestic transport emission).

2.1.2 Testo 350 Maritime:

Using Testo350 , a portable emission and combustion analyzer instrument the emission from a particular vessel can be measured periodically. It is the first portable exhaust gas analysis system for the measurement of exhaust gas emissions according to MARPOL Annexe VI and NOx Technical Code 2008. The testo 350 MARITIME has the following certificate: GermanischerLLoyd (GL) certificate no. 37811 - 12 HH, according to MARPOL Annexe VI and NOx Technical Code 2008. The exhaust gas analyzer additionally fulfils the guideline on marine equipment and has the MED conformity mark 0098/12. Gas sampling takes place with a special, easy-to-install sampling probe. The certified and durable electrochemical gas sensors (ECS) record the concentrations of the exhaust gas components O2, CO, NOx (NO + NOX separately) and SOX highly accurately and with long-term stability. CO2 is recorded using the certified IR measurement principle. The advantages of using testo 350 are 1) Periodic examinations and intermediary examinations, 2) Direct measurement and monitoring on board 3) Simplified test and measurement procedures. In addition to this, you can use it for official NOx-monitoring measurements to check the NOx limit values prescribed in MARPOL Annexe VI on board.

Fig.2Testo 350 instrument

Table:1Measured data for research vessel and cargo vessel

| **Ship type** | **Total value of measured NOx(g/kwh)** | **Total value of measured SOX(g/kwh)** |
|---|---|---|
| Research Vessel | 10.9 | 0.25 |
| Cargo vessels | 17.2 | 3.97 |

## 2.2 Ship Emission Calculator

It is a web based tool created by the National Technical University of Athens, Laboratory for Maritime Transport for calculating the exhaust gas emissions (CO2, SOx and NOx) of specific types of ships under a variety of operational scenarios. The analysis of emissions of the world fleet database has produced various statistics of emissions for various ship types and size brackets under a variety of scenarios. Such statistics may be useful for supporting specific policy recommendations on this subject, before the IMO and/or other bodies. We have calculated by entering our own details results are got.

The most basic results as regards how emissions were calculated can be summarized as follows:

(a) $CO_2$ emissions do not depend on type of fuel used or engine type. One multiplies total bunker consumption (in tonnes per day) by a factor of 3.17 to compute CO2 emissions (in tonnes per day).

(b) SOx emissions depend on type of fuel. One has to multiply total bunker consumption (in tonnes per day) by the percentage of sulphur present in the fuel (for instance, 4%, 1.5%, 0.5%, or other) and subsequently by a factor of 0.02 to compute SOX emissions (in tonnes per day).

(c) NOx emissions depend on engine type. The ratio of NOx emissions to fuel consumed (tonnes per day to tonnes per day) ranges from 0.087 for slow speed engines to 0.057 for medium speed engines.

There have been two distinct categories of runs. One concerned those based on the web tool and the other was based on the world ship database (Lloyds- Fairplay). The analysis is based on the Lloyds-Fairplay world ship database for 2007 and produces various emissions statistics of the following major ship types: bulk carriers, crude oil tankers, container vessels, product/chemical carriers, LNG carriers, LPG carriers, reefer vessels, RoRo vessels and general cargo ships. The main outputs from this analysis for each ship type-size bracket are the emitted grams of emissionsper tonne-km and an estimate of the total emissions are calculated. The below table.2 illustrates the amount of NOx and SOx calculated using the web tool.

Table:2 Calculated data for research vessel and cargo vessel

| **Ship type** | **Total value of modeled NOx**(g/kwh) | **Total value of modeled SOx**(g/kwh) |
|---|---|---|
| Research vessel | 11.75 | 0.7 |
| Cargo vessel | 18.95 | 4.95 |

### 2.3 Satellite Image observations

The principal gaseous and particle emissionsfrom ships include CO2, H2O, NOx, SOx, CO, unburnedhydrocarbons, and particulate matter. The plumes from shipstacks effectively release these species at relatively highlocal concentrations into the marine boundary layer. Whileall these components do have an impact on the atmosphere and on climate in this paper we concentrate on all these emissions as this can nowbe observed by satellite measurements.NOx and SOx emissions are dominated by anthropogenicsources, such as heating, electricity generation, and roadtransportation systems. To a lesser degree, shipping also contributesto the observed concentrations [5]. To assess accuratelythe impact of the emissions from shipping on the troposphere,and predict its future impact, detailed knowledgeof the emission patterns is required. Remote sensing measurements of NOXand SOXfrom spaceoffer the potential for unique insight into this issue. NOX and SOXfrom anthropogenic emissions has been detected in GlobalOzone Monitoring Experiment (GOME) measurementsbut the NOX signature of particular ship is difficultto identify unambiguously because of the low spatialresolution of the GOME2 instrument (40 x**40 km$^2$** (Metop-A), 80 x **40 km$^2$** (Metop-B)) .It was developed by joint contract from EUMETSAT and the European Space Agency (ESA) [6], [7], [8]. GOME 2 is used to get a detailed picture of total atmospheric content of ozone and the vertical ozone profile of atmosphere. During an orbit, GOME 2 measures a spectrum of 240 -790nm at a high spectral resolution between 0.2- 0.4 nm. It has 4096 spectral points from four detector channels.The swath width of GOME 2 is 1920 km at 40 m * 80 km and narrow width swath of 960km at 40m * 40km providing global coverage daily [9]. MetOp is a sun synchronous orbit having an equator crossing time of 9:30 LT. Fig.3 shows the NOx emissions from ships in the Indian Ocean.

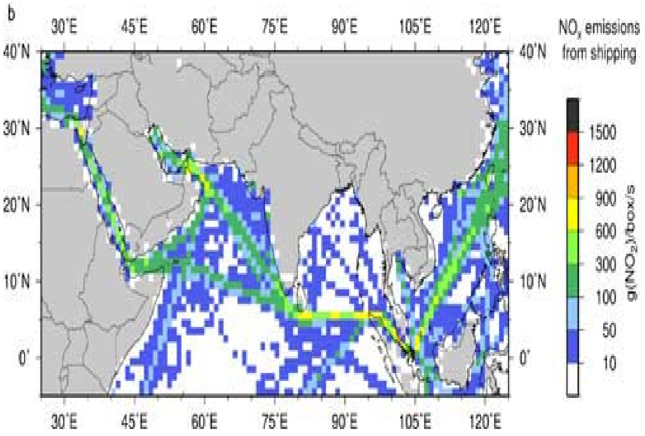


Fig.3 NOx emissions from ships in the Indian Ocean

## 3. RESULTS AND DISCUSSION:

The emissions measurements have been collected along the coramendal coastal region of India from shipping. This coastal region compromises of major ports such as Krishnapatinnam, Ennore, Chennai, Karikal and also have Godavari oil field near Kakinada by which this area has a large volume of traffic between Vizagapatinam to Karikal. Chennai port handling 150,000 tonnage of cargowith an average of 2500 vessels.The NOX and SOX emissions along this cost are favorable for tropospheric observations from space. In this paper two comparison studies have been made such as

- Comparing the ambient air quality measurements with the satellite data as this both depends on a location wherever the ship travels.
- Comparing the onboard measured values (Testo 350) with the web tool by loading the details of the ship by which emission levels are being calculated from ship.

Fig.4 shows the ship track along which the samples have been collected for this study.

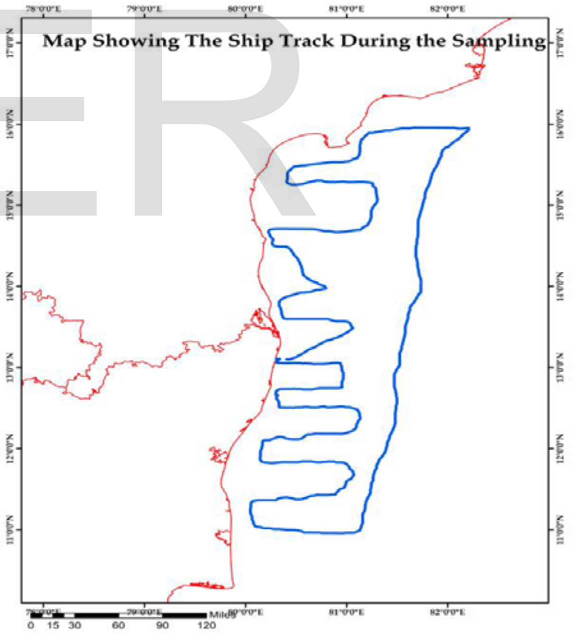


Fig.4 Ship Track during sampling

The first comparison study illustrates the use of regional air quality models to assess the impact of ships at locations close to ports and shipping routes. A comprehensive increase in the emissions (NOX, SOX) shows impact of peak concentrations near port areas. The ambient measurements measured along the ship track have been observed from the GOME 2 instrument values[10], [11], [12]. The results more or less shows as the emission levels near the port are is comparatively high in the ship track we choose. In this study we present the first detection and quantification of ship NOx emissions from satellite [13]. The line of enhanced NOx and SOx emissions in the Bay of Bengal as seen in the composite of cloud free GOME observations clearly coincides with the distinct ship track from Vizagapatinam to Karaikal. We used seasonal differences in the wind direction to derive the mean emission levels of ship exhaust. This conclusion is consistent with ongoing research showing that better inventories are only part of the solution to better evaluation of ship emissions impacts on air quality or climate change. The most important recommendations from this research address improved modeling; however, recommendations are also offered for better plume studies and testing [14], [15]. Modeling methodologies will need to consider whether emissions reductions can be computed by simply adjusting emissions factors according to average reductions or whether new information about the vessel, engine, and emission control technology operation will be needed [16]. This will also be important to address concerns about deterioration of engine or control technology performance over time; further longitudinal analyses of emissions can be pursued to predict emissions and validate or certify reduction techniques [17], [18]. Table.3shows the ambient air quality measurements collected during our cruise.

Table.3 Ambient air quality measurements

| **No. of days** | **SOx**(µg/m3) | **NOx**(µg/m3) |
|---|---|---|
| Day 1 | 20.71429 | 27.85714 |
| Day 2 | 21.42857 | 27.14286 |
| Day 3 | 19.42857 | 27.71429 |
| Day 4 | 23.85714 | 32 |
| Day 5 | 21.678 | 31.5677 |
| Day 6 | 22.965 | 28.6557 |
| Day 7 | 18.932 | 26.321 |
| Avg | 21.28622 | 28.75124 |

An update of the global NOx emission inventory from shipping is estimated as 6.87 Tg(N) per year with a 1º*1º spatial resolution. Daily averaged SOX and NOX values are available at 0.25° * 0.25° spatial resolution [19]. Here we provide a rough estimate which has to be developed for further study by fine tuning the pixel resolution to estimate the emission value at a particular point[ 20]. The NOx and SOx emissions along the coast are higher on the port areas. The data source more collected near the Chennai and Ennore port areas shows high value of NOX emissions. These two ports have major ship traffic and also it handles MBC to VLCC in the coramendal cost and being major sources of NOx emissions from ships [21]. Fig. 5 shows the NOx emissions at the port areas. Fig.6 shows the satellite data image acquired for the ship track we chose.

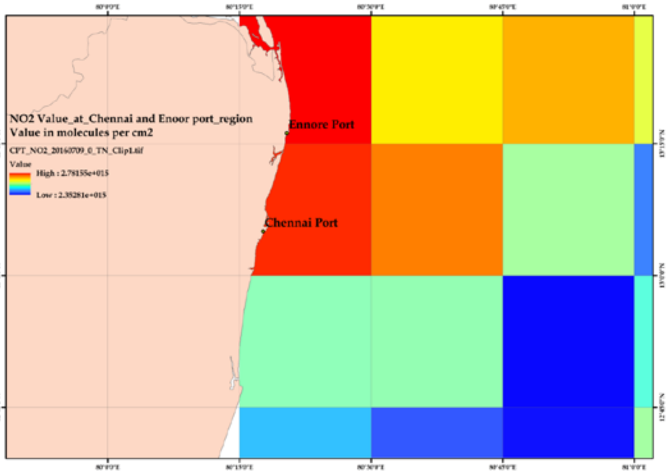
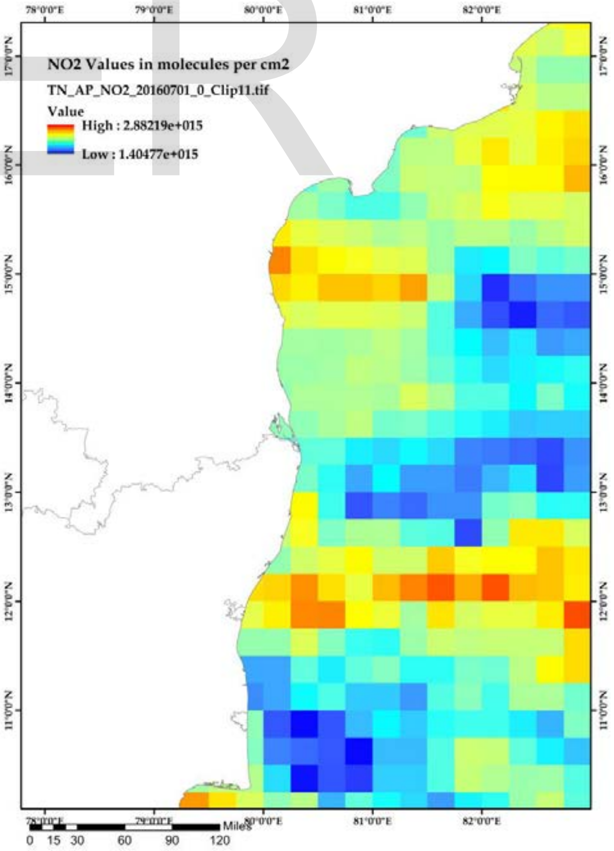


Fig. 5 NOx values at ports in molecules per cm²



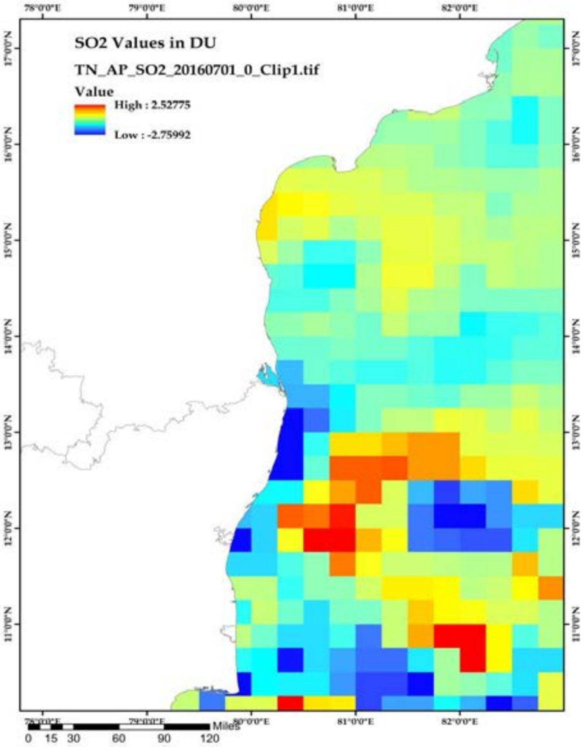


Fig.6NOx and SOx values in molecules per cm$^2$

The next comparison study made between the measured value using Testo 350 and the values calculated using the web tool. The individual NOx and SOx emissions from the ship have been measure using the portable analyzer Testo 350. The ambient air quality values measured using the air analyzer and Testo 350are compared with the web tool calculated values. The web tool values differ by±20% of that of the original measured value.The details of the ship are loaded in the ship emission calculator web tool so that it gives the NOx and SOx emissions which are compared with the above.

Table 4.Comparison between the Testo 350 and web tool

| Ship type | Averaged NOx(g/kwh) | | Averaged SOx(g/kwh) | |
|---|---|---|---|---|
| | Measured | Web tool | Measured | Web tool |
| Research Vessel | 10.9 | 11.75 | 0.25 | 0.7 |
| Cargo Vessel | 17.2 | 18.95 | 3.97 | 4.95 |

## 4. CONCLUSION

The satellite data present here show that the emissions from ships do have a major part in releasing the NOx and SOx levels in the marine boundary layer. The pixel value of GOME 2 give the spatial averaged (0.25˚ * 0.25˚) value of NOx and SOx. The observed emission patterns provide similar inventories as the satellite data. The accuracy of the space based emissions could be much more improved with an accurate spatial resolution so that the emissions of a particular ship can be found in future. Use of more GOME 2 data and some possible facilities to identify the ship tracks in other region of the world will be useful. Furthermore, the emission study can also be done with the other satellite data from MODIS instrument onboard Terra and Aqua satellite, VIIRSinstrument on board the Suomi NPP satellite and future Joint Polar Satellite System (JPSS) satellites with improved spatial resolution might even allow the detection of further ship tracks in near future. This can also be studied using the AIS(Automatic Identification System) data collected.

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