STATE OF THE ART – AIS BASED EMISSION CALCULATIONS FOR THE BALTIC SEA SHIPPING

Jukka-Pekka Jalkanen[1], Anders Brink[2], Juha Kalli[3] and Tapani Stipa[4]

[1]Finnish Meteorological Institute, Air Quality, P.O. Box 503, FI-00101 Helsinki, Finland
[2]Åbo Akademi, Process Chemistry Center (CMC), Tuomiokirkontori 3, FI-20500 Turku, Finland
[3]University of Turku, Centre for Maritime Studies, P.O. Box 181, FI-28101 Pori, Finland
[4]Finnish Institute of Marine Research, P.O. Box 2, FI-00561 Helsinki, Finland

Abstract: A system utilizing the Automatic Identification System (AIS) messages is used to estimate the exhaust emissions of ship traffic in the Baltic Sea area. Data analysis for 2006-2007 indicates that existing emission inventories underestimate annual NOx release and fuel consumption of maritime traffic.

Key words: *Ships, exhaust emissions, NO_x, Automatic Identification System, AIS, Baltic Sea, Marine Traffic.*

1. INTRODUCTION

Baltic Sea is a busy place. At any given moment there are over 2000 vessels anchored or en route to different harbors and about 3500-5000 vessels can be seen in the area each month. Traffic numbers of this magnitude pose a significant challenge to vessel traffic control centers in order to keep track of every ship and help guide them to safe passage through shallow waters on the Baltic Sea. While collisions and groundings are a constant risk for the delicate environment, the effects of marine traffic can be seen even without accidents in the form of atmospheric emissions of eutrophying substances like NO_x.

In order to reduce the risk of collision between ships the International Maritime Organization (IMO) stipulated that navigational aid called the Automatic Identification System (AIS) must be used in ships globally:

"The regulation requires AIS to be fitted aboard all ships of 300 gross tonnage and upwards engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004"
IMO Regulation 19 of Safety Of Life At Sea (SOLAS) agreement, Chapter V

The AIS acts as a navigational aid for ships much like the radar transponder system used in airplanes is used by the air control towers to keep track of air traffic. The AIS system sends out GPS coordinates of the vessel along with other ship specific data every few seconds, depending on the speed of the vessel. The position of the fast moving ships is sent out every two seconds, while those anchored in harbors in every ten minutes. Using these messages it is possible to track every vessel and obtain information of its position, speed, course and destination. Existing methods to estimate emissions of the ship traffic usually rely on statistical information consisting of the number of vessels, their average size, the average distance traveled between ports and the amount of fuel bunkered during harbor visits. The position reports sent out by the AIS system guarantees that the location of the ship is always known, thus obviating the need to use average route distances as a guideline for emission studies. Estimates done based on this information will lead to a general picture of the emissions completely neglecting changes in ship speed, use of emission abatement techniques, weather effects and true ship position along different fairways. It also gives an unrealistic description of geographical distribution of emissions. The time interval for AIS-based emission estimates is one second and this is the time resolution the user can achieve regarding the ships' position and exhaust emissions. In practice, longer summation periods are used, like 15 minutes used in this introduction.

2. BASIS OF THE EMISSION CALCULATIONS

Detailed and up-to-date information about each vessel must be at hand, especially technical information about the main and auxiliary engines, boilers and generators. When the speed and technical data of the vessel are known, estimate of its level of main and auxiliary engine use is computed based on current speed – design speed relationship and vessel's fuel consumption and exhaust emissions are calculated. These result in a ship-specific inventory. For this purpose, few basic formulae can be used in estimating the required pushing power. (ITTC Recommended Procedures, 1999) The primary source of ship technical data is our internal database of vessels which consists of details for ~17000 vessels and their engines. If the vessel is not included in this database, the program makes an automated network search using the Lloyds ship register for necessary information. The internal database is a synthesis of many data sources containing measured emission factors for ships having an environmental certificate, but it also includes information of possible abatement techniques installed in ships. Currently there are 13 abatement techniques included and NO_x reduction factors are assigned for each technique. Different emission factors for different types of engines (2-stroke/4-stroke) engines are used and further enhancements are already being implemented.

Different ship types have a different ways of using their engines, especially during harbor visits and they may use different fuel during harbor stays than on open sea. The electricity requirements of onboard navigation equipment, air conditioning, heating water, cargo loading/unloading and cargo heating/cooling vary depending on the type of the ship. Our program uses different auxiliary engine profiles for various vessel types and it will be developed further. Energy demand of a large cruise ship with more than a thousand air-conditioned cabins is remarkably different than a bulk cargo carrier. Auxiliary engine use plays predominant role in modeling the harbor emissions, because they are used to generate electricity during harbor stays while main engines do not contribute harbor emissions significantly during hoteling.

At its current state, the program takes weather effects into account by applying additional power requirements in bad weather areas with high values of significant wave height. The wave height data is obtained from the Wave Analysis Model (WAM) (Komen, Cavaleri, Donelan et al., 1994) run by the marine researchers at the Finnish Institute of Marine Research (FIMR). The increased power demand for a ship, caused by waves, is taken into account by the formulae of Townsin et al. (1993) The additional power requirement depends on parameters describing the three-dimensional structure of the hull and the direction of the waves and hence it is different for example for cargo and passenger ships.

3. QUALITY CONTROL OF EMISSION ESTIMATES

At its current state, due to lack of experimental data of NO_x emissions of each ship, only indirect comparisons to real world values can be made. The fuel consumption values produced by the program can be compared with the data provided by the ship owners. The results reveal that the combined fuel consumption of main and auxiliary engines of passenger ships is quite close to reality, but more fuel data is needed from the ship owners to make conclusive judgments. Fuel consumption data for various ship types would be most welcome to facilitate the enhancement of the system. Most of the cases compared so far show ~20-25% under prediction of calculated fuel consumption probably due to missing sea current, ice, bottom and fouling effects. In one of the cases program is quite accurate, predicting monthly fuel consumption within 15 kilograms of the real value, but a lot of work still remains. Experimental measurements of different types and ages of ships are planned to allow direct comparison of NO_x levels.

4. EMISSIONS BY AREA

Real time reception of the AIS data flow enables real time tracking of ship emissions. Figure 1 shows an example of a snapshot taken from one of the 15 minute emission summation periods. From this figure, it can be seen that largest emissions occur on Danish straits, Kiel canal and on the Gulf of Finland. During this one quarter of an hour period about 11 tons of NO_x was released in ship exhaust fumes. Summation of individual emissions from one month's period (March 2006) leads to NO_x emission of 32.3 kilotons and its geographical distribution is shown in Figure 2, where the fairways are easily recognizable. Analysis of a full year of AIS data results to 370 kilotons of NO_x emitted in the Baltic Sea area. The 370 kt NO_x estimate is bound to be on the lower side, because several uncertainties were played down in a way that they would lead to smaller NO_x emission than in reality in order to get a baseline estimate. These include the effect of ice during the winter months or shallow water bottom effects which are not included in the model yet.

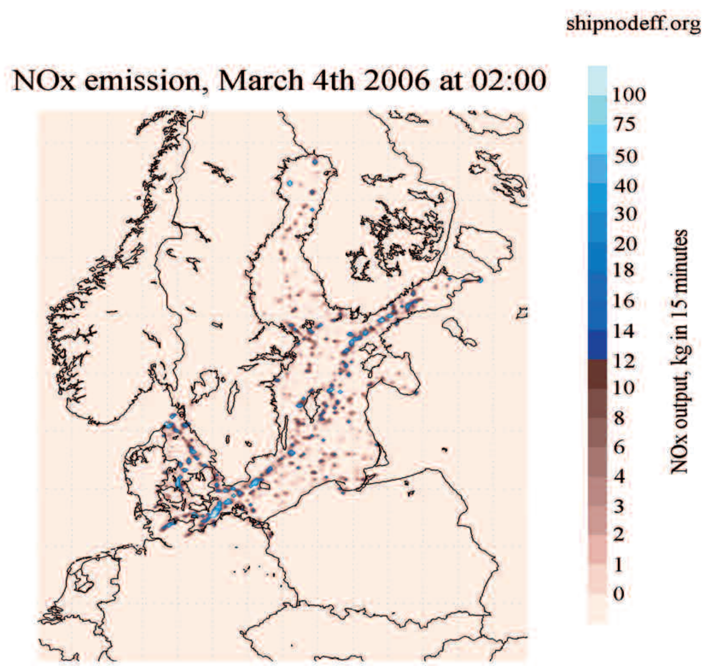

Figure 1. NO_x emissions of ship traffic in the Baltic Sea area during one 15-minute period on March 4th 2006.

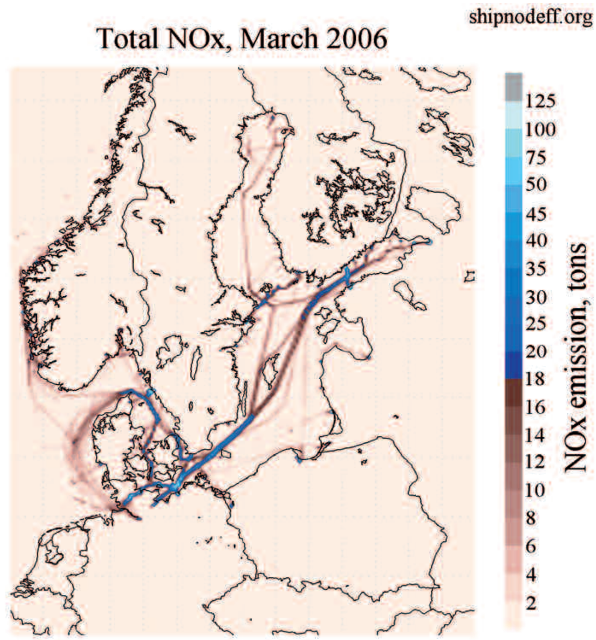

Figure 2. Total NO_x release of ship traffic during March 2006.

The program can be used to track ship emissions all over the world, not just the Baltic Sea, provided that AIS transmissions from that area are available. Both spatial and time resolution of the emission grid can be increased to study for example harbors or preservation areas in detail.

In addition to the geographical distribution of emissions it is possible divide ship emissions based on flag state, ship size, type, age, engine type and so on. It is also possible to study traffic densities on specific regions. This gives a good basis for policy making and facilitates the construction of possible emission trading schemes.

5. FUTURE SCENARIOS

Using the year 2006 estimate of 370 kilotons of NO_x as a baseline, several projections to the year 2030 were considered. Assuming the "business-as-usual" scenario with an annual traffic growth of 2.6 % in ship numbers and taking different renewal rates and NO_x abatements through technical development of engines into account, the NO_x release in the Baltic Sea area in 2030 would reach 531 kt per year. If the traffic growth of 5.2 % is used, the NO_x levels may reach 886 kt per year in 2030. The AIS systems have been active only for about three years, which makes the long term prediction of traffic trends challenging, but it seems that ship traffic increase was well over 5 % during 2006-2007.

The effects of IMO "three Tier approach" (IMO Briefing 2, 2008) to curb NO_x emissions were investigated and it was found out that only the most stringent actions for limiting ship NO_x emissions are able to negate the effect of traffic growth and turn the NO_x emission trend downwards. Analysis of this kind was made as a part of Baltic Marine Environment Protection Commission (HELCOM) submission to IMO (Stipa, Jalkanen, Hongisto, Kalli and Brink, 2007) when revision of MARPOL Annex VI was considered.

As a part of the revision of MARPOL Annex VI, IMO countries agreed to set stricter limits for NO_x emissions from ships. Marine Environment Protection Committee of IMO agreed in 57th meeting that in the Emission Control Areas (ECA), NO_x reduction from 17 gkWh^{-1} to 14.4 g/kWh is mandatory for engines constructed after 2011. After 2016 only maximum of 3.4 gkWh^{-1} is allowed for new ships in ECA areas. This practically makes catalytic converters compulsory for ships sailing in NO_x ECA areas, provided that low sulphur fuel can be produced at sufficient quantities. It is noteworthy that IMO also requires modification of old engines built in 1990-2000, so that they conform to existing NO_x limits of 17 gkWh^{-1}.

Starting from 2010, maximum allowed sulphur content is reduced from 1.5% to 1.0% in SECA areas. Sulphur limitations are tightened further from 1.0% to 0.1% starting in 2015. Outside SECA areas, on a global scale, the sulphur cap will be 0.5% from 2020 onwards, subject to a feasibility review on 2018. If this review is negative, then the limit will be postponed for five years (2025).

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