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Atmospheric Chemistry and Physics Discussions

Interactive comment on "A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area" *by* J.-P. Jalkanen et al.

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Response to reviewers' comments on:

Jalkanen Jukka-Pekka, Brink Anders, Kalli Juha, Pettersson Heidi, Kukkonen Jaakko and Stipa Tapani, "A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area", ACPD 9 (2009) 15339.

General comments by the authors

We have improved the English language throughout the manuscript. Some overly long paragraphs have been divided into two, for a better readability.

Referee 1, general points

However, the model description lacks a clear mathematical formulation, hindering replication of results. Referring to Figure 1 is not sufficiently precise. Equations for the estimation of emissions and fuel consumption should be provided, linking the described factors (engine power, emission factors, wave penalty etc) to the emissions.

Also, the general structure of the paper can be improved. In particular, the model description and the input data are not clearly separated. Prior to publication, it is suggested that the paper is reworked to more clearly separate between model description, input data, results, discussion and conclusions.

Authors, general points: A more extensive set of equations was added to Section 2.3

We have added a separate extensive section of input data regarding the ship properties (Sections 2.1 and 2.2), before the model description.

The required model input datasets have been clearly presented in Fig. 1 (as ellipsoids). Their structure has been described in more detail in the revised manuscript (in Section 2.3). Some of the section headings have been revised to be clearer in this respect and the overall structure of the text has been improved.

Referee 1, point 1: 15341, 20-21: What is the source for the vessel number - AIS?

Authors, point 1: The vessel number, on which the number of different ships is based on, is the Mobile Maritime Service Identity (MMSI) number included in AIS messages. The estimate is not based on just the IMO number, since small vessels do not necessarily have an IMO number.

This is now clarified in the Section 1.

Referee 1, point 2: 15341, 25: It is commonly recognized that the most significant shortcoming in the existing methods are related to ship operational profiles; engine load/ship speed, days at sea etc. This should be mentioned.

Authors, point 2: This is now mentioned in Introduction.

Referee 1, point 3: 15342, 21: Is this generally true, or limited to European or Baltic studies?

Authors, point 3: This statement is given in ENTEC 2002 report, which is said to be the basis for the 2005 ENTEC study:

“ Due to the large number of vessel movements world-wide on an annual basis; the complexities of the data analysis and level of disaggregation required for this project; a sample of the data was supplied. The data was for four discrete months to reflect seasonal variations in shipping activity. The months selected were January, April, July, October 2000, to represent movements representative of winter, spring, summer and autumn. The final emissions values were then multiplied by three, to give annual emissions estimates.”

In 2005 Entec report it is not stated, whether this assumption still holds, but it is not refuted either.

The issue of inaccurate description of ferry traffic in the Entec study:

“The movements database does not detail all ferry movements. i.e. where a ferry makes multiple callings at the same port in one day, only the first movement of that vessel is likely to be recorded. Therefore, all ferries were removed from the initial analysis and investigated separately.”

The approach taken by ENTEC was to estimate the number of feasible port calls based on shortest distance between departure/destination ports and the average speed of the vessel. In the ENTEC report it is not stated that this method is restricted only to the Baltic Sea. Our assumption is that it is applied to all sea areas included. The use of AIS data removes these problems, since the emission calculation can be automated, which makes more efficient use of resources and removes the uncertainty in the time spent at sea.

The following sentence was inserted to Section 1:

”A substitutive method for ferries in the EU area was used in the ENTEC study, which was based on estimated number of port calls during each day, which could lead to significant inaccuracies, especially for relatively short-distance sea routes, such as the traffic across the Gulf of Finland between Helsinki and Tallinn, for which the passenger traffic is intensive. ”

Referee 1, point 4: 15343, 23: A brief overview of the structure of the paper should be provided, “In section 2. . . , In section 3. . . . Etc”.

Authors, point 5: A brief overview of the overall structure of the paper was added to the end on the Introduction.

Referee 1, point 6: 15343, - : Section 2 should more stringently describe the model developed. Emission factors and other input data should be described in the preceding sections. Mathematical formulations are needed.

Authors, point 6: The input data for ships and the assumed efficiency of different abatement techniques were added to Section 2.1 (Ship properties). A more detailed description of the needed equations was added to Sections 2.3 and 2.3.1.

Referee 1, point 7: 15343, 27: A description of the “the internal ship database” as well as Lloyds is needed. In particular, the difference between the two and how much more information is gathered in the internal database, and for how many ships. Some information is scattered throughout the paper, but this should be collected and presented in a more structured manner.

Authors, point 7: New sections (2.1 and 2.2) have been added to better describe the input data, which are used in emission calculations. The final for of the power-estimate has been written out more clearly. Also a motivation for the use of the simplified version of the Power-velocity relation has been added.

Referee 1, point 8: 15344, 2: What information is available in the AIS data for determining ship type?

Authors, point 8: In AIS message type 5, which reports the static, voyage related data, there is a field for ship type in numerical form. This information can often be quite vague, so it cannot be used as a primary means of determining the ship type, but it can provide additional information in unclear cases.

Referee 1, point 9: 15345, - : Section number heading is wrong?

Authors, point 9: This has been corrected

Referee 1, point 10: 15345, 17: Why is a "safety margin" used? The motivation should be explained. Does this margin conflict with the explicit modeling of wave resistance?

Authors, point 10: One reason for adding a safety margin was that for some vessels the velocities transmitted over the AIS system exceeded the design speed entry in the Lloyd's register. The safety margin does not conflict with the wave resistance model. The use of MCR as the power needed to achieve the maximum velocity is partly related to waves, since this velocity should also be reachable with moderate wind and waves.

The motivation for using the safety margin is now explained in Section 2.3.1.

Referee 1, point 11: 15345, 25: What is the relation between Pmax, P, installed power, and fuel consumption? Mathematical formulations are needed.

Authors, point 11: Clarifications on this issue have been added. Pmax is assumed to maximum continous rrating, which here is 80% of the installed power. The fuel consumption is calculated assuming that 200 g fuel is required to produce one kWh.

Referee 1, point 12: 15345, 26: How, is k determined in this model?

Authors, point 12: An equation has been added describing the calculation of the ship specific constant k.

Referee 1, point 13: 15346, 17: If the database contains data on AUX engine size for

85% of the vessels, why then are the fixed values described above used? The results indicate that the AUX fuel consumption is consistently overestimated.

Authors, point 13: We agree with Referee 1. The auxiliary engine profiles certainly require some more attention, especially for RoPaxes. The current method of estimating the auxiliary engine power was constructed for passenger ferries/RoPaxes in the Baltic Sea at a time when it was believed that auxiliary engine information would be very difficult to come by. Inside the RoPax ship type a distinct division to at least two different kinds of RoPaxes can be made;

1) a ship built primarily for transporting people and some cargo and 2) a ship primarily transporting cargo, but also some passengers.

The AUX engine utilization inside STEAM is mainly for type 1 RoPax and describes less well type 2 RoPaxes.

At a later stage of the work it was discovered that AUX engine information could be available, albeit a significant effort would be required to collect it. This is now done and we are currently working to collect the boiler data. We conducted some preliminary testing with Jan 2007 data, but we have not run all the data with the new algorithm, yet. For testing purposes, we also implemented the Entec AUX engine scheme and investigated the scheme described by Cooper (Cooper DA, Atm. Env., 37 (2003) 3817.) The ENTEC scheme significantly changes the AUX engine profiles of all ships, while the method of Cooper only applies to harbor emissions of RoPaxes. The difference in emissions and fuel consumption between the existing scheme and the ENTEC scheme is around 10-12 % (lower) on the inventory level covering all the ships in the Baltic Sea. However, it must be borne in mind that the ENTEC scheme does not include the effect of boilers at all, which according to Cooper, are significant (18-106 % for the seven ships investigated by Cooper) when compared to the total AUX engine fuel consumption.

The ENTEC scheme does not agree very well with the AUX engine usage reported by Cooper, while the Cooper scheme is less accurate for type 2 RoPaxes. Since the Cooper scheme is based on the DWT of RoPaxes, it leads to large AUX engine usage for type 2 RoPaxes, which usually have larger deadweight than the type 1 RoPaxes. To our experience, exactly the opposite should happen.

The direct comparison of predicted and reported fuel consumption of auxiliary engines and boilers is shown in Figure 1. The ship in Figure 1 is a 60 000 GT type 1 RoPax, which mostly carries people, but also some cargo. Five fuel consumption profiles are shown, three of them come from the ship owner (Aux, Boilers, Aux+Boilers) and two predictions made with the current AUX engine profile (Cyan, for the whole year 2007) and the ENTEC profile (Red, for January 2007). As can be seen, there is a clear seasonal variation in the use of boilers and auxiliary engines. The use of ENTEC profile for AUX engines actually makes predictions worse. Direct application of the AUX profile described by Cooper is problematic since it was developed for harbor emissions and is not necessarily directly applicable to this case, because the ship operates outside harbors most of the time.

"The use of boilers has a strong seasonal dependence; it has a minimum in summer months and a maximum during the winter period. The reason is probably the energy required by heating service water; less energy is required during summer, due to higher ambient temperatures. Exactly the opposite seems to be valid for auxiliary engines, as the fuel consumption of the auxiliary engines in the investigated RoPax vessels has a maximum in summer and a minimum in winter, most probably due to the air conditioning required to cool the passenger areas in summer. These two factors have therefore a counteracting influence on the seasonal variation of the fuel consumption. The assumption of a constant value for auxiliary engine use and boilers is therefore reasonable, but could be refined in the future."

The paragraph above was added to Section 2.3.1 (Engine power estimates for individual ships), but the figure 1 presented here was not added to the manuscript.

Referee 1, point 14: 15347, - : The effect of waves should be mathematically linked to the fuel consumption. How does eq. 4 and 6a/b relate to the emissions? This is unclear.

Authors, point 14: This has been clarified in section 2.3.3 by adding an equation (Eq. 8), which links the penalty caused by waves to predicted engine power level.

Referee 1, point 15: 15351, 14: Reference to Figure 2 is missing.

Authors, point 15: Figure 2 and a short paragraph describing the RoPax5 monthly fuel consumption comparison was deleted from the manuscript according to the request of Referee 2.

Referee 1, point 16: 15352, 1: There is no "section 2.2.1".

Authors, point 16: Section numbering has been corrected.

Referee 1, point 17: 15352, 10: Statement about the effect of waves is not evident in the presented results.

Authors, point 17: A paragraph and a figure describing the effect of waves to hourly fuel consumption were added. Although it is probably unnecessary to include the effect of waves on an inventory level of large geographical areas (as it is negligible), it cannot be overlooked on local level. If we are interested in ship-specific fuel/emission inventories on a voyage basis, or the time resolution is increased significantly, then waves cannot be left out. One should also note that convincing the ship owners of the fact that there is a sufficient level of detail inside the model is important.

Referee 1, point 18: 15352, 17: "The effect of waves.." should read "The estimated effect of waves. . . "

Authors, point 18: This has been corrected.

Referee 1, point 19: 15352, 18: "The increase of.." should read "The estimated increase of. . . "

Authors, point 19: This has been corrected

Referee 1, point 20: 15352, 21: While the inclusion of the wave-parameter is highly interesting, the model results seem to suggest that the current implementation do not improve the model results (rather to the contrary). This should be discussed more thoroughly, and suggestions for improvement should be made.

Authors, point 20: Just like illustrated above on point 17, the inclusion of the effects of waves is probably not needed on an inventory level. However, on a local scale where individual ships are investigated or smaller sub areas of the Baltic Sea are studied, these effects become more pronounced. This feature can be found also on other emission inventories, which may on a continental level be similar, but can be quite different when viewed on a local scale. From a regional air quality modeler's point of view waves may not be that big an issue, but STEAM was not built only for that purpose. It can also be used as a decision support tool, for example as a first link in estimating the costs and benefits of different policy options concerning ship traffic. Once validated against measurements, it can be used as a baseline estimate in constructing emission based fairway dues systems, environmental impact assessments of port areas and so on.

In order to conclude how well the effect of waves is predicted, detailed information of the fuel consumption and emissions of dozens of ships is needed. These should represent various ship types and sizes. Since this approach requires extensive cooperation and field work with the ship owners, the process may take some time. We are currently working with the ship owners to validate the STEAM model against experimental measurements.

To better illustrate the effect of waves on the fuel consumption, a new figure was added with a paragraph discussing the increase in fuel consumption during a specific voyage.

Referee 1, points 21, 22: 15354, 1: Can the large differences between ships built after 2000 after 1990 be explained solely be the NOx curve? A relevant point in this discussion is the number of hours spent in the Baltic for the different ships. The connection (or

lack of connection) between number of ships and number of ship-hours for the different segments should be discussed.

15354, 10-20: Again, the relevance of ship-hours vs ships should be discussed. Also, this information is highly relevant in the evaluation of emission reducing measures and legislation. This could be discussed.

Authors 1, points 21, 22: A paragraph of text and a new table describing these issues have been added to Section 3.3

Referee 1, point 23: 15354, 25: How does the distribution in figure 10 compare to the flag distribution for the world fleet?

Authors, point 23: The flag distribution of the global fleet was obtained from UNCTAD 2008 statistics and it is presented in Figure 2 together with the NOx emission.

Regardless of the fact that Nordic countries have small fleet, their share of NOx emissions is significant. This figure was not added to the manuscript, but is shown here as requested by Referee 1.

Please also note the Supplement to this comment.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 15339, 2009.

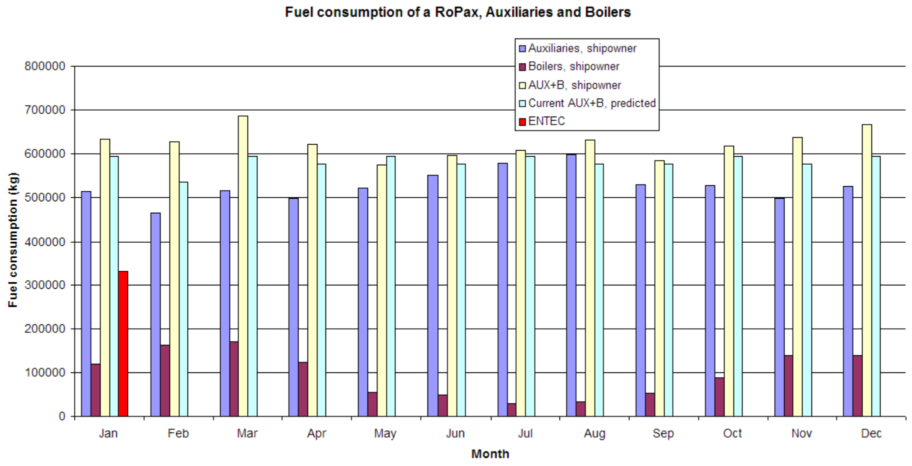

Fig. 1. An example of the fuel consumption of a 60 000 GT RoPax auxiliary engines and boilers. Five fuel consumption profiles are shown, three from the ship owner (Aux, Boilers, Aux+Boilers) and two modeled.

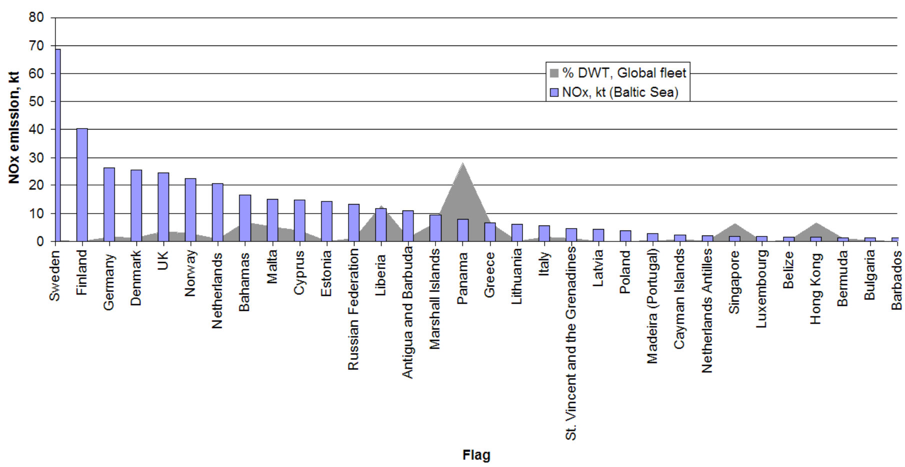

Fig. 2. Ship NOx emissions in the Baltic Sea area (sorted by flag) combined with the flag distribution of global merchant fleet.