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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 3, general comments, point 1: Clear definition of the area under study Data source description Processing description Descriptive statistics analysis of the input data in separate section

Authors, general comments, point 1: Following paragraphs were added to Sections 1 and 2.

"The Baltic Sea is defined as the area including the Baltic Sea, the entrance to the Baltic Sea bounded by the parallel of the Skaw in the Skagerrak 57.74N, 10.6325E."

"The data for this study has two main sources. The vessel movement data comes from the AIS networks of Finland, Sweden, Denmark, Germany, Poland, Latvia, Lithuania, Estonia and Russian Federation surrounding the Baltic Sea. The technical details used in this study are taken mainly from the Lloyds register, but they are complemented with data from various authorities, ship owners and other public sources."

The process description is shown in Figure 1 of the manuscript, but detailed process description regarding the AIS data handling and error analysis will be left for a separate paper. The description of the development of these tools is rather long and beyond the scope of this paper.

Referee 3, specific comments, point 1: Actually it is engine load that is based on the relationship of the instantaneous speed to the design speed.

Authors, specific comments, point 1: This has been corrected.

Referee 3, specific comments, point 2: "For a RoPax vessel, the predicted and reported values of fuel consumption agreed within an accuracy of 6%." It sounds that for any RoPac vessel, the difference will be 6%. This sentence should to be revised to avoid this confusion.

Authors, specific comments, point 2: This paragraph (and former Figure 2) were removed from the manuscript as requested by Referee 2.

Referee 3, specific comments, point 3: Please give the source and/or citation of these numbers and specify the size limit of the vessels included in the numbers.

Authors, specific comments, point 3: The numbers presented are results of the AIS data analysis conducted in this work. To clarify the source of these numbers and their applicability to vessels of different sizes, Section 1 was rephrased to include the following lines:

“Based on the analysis of this work, there are more than 2000 vessels anchored or en route to different harbours at any given time, and about 3500-5000 different vessels are in operation in the Baltic Sea area every month. These values are based on the unique Mobile Maritime Service Identity (MMSI) numbers sent in the AIS messages; these include only the vessels with an active AIS transmitter onboard. In addition, a substantial number of small (< 300 GT) vessels exist, which are not required to use AIS; for such vessels the use of AIS is voluntary. ”

Referee 3, specific comments, point 4: "...the typical maximum range of an AIS base station is therefore from 50 to 90 km...". Please describe how the gaps outside of the 90km AIS range, e.g. in the middle of Baltic, are filled. AIS data are the foundation of this modeling system. It will be useful if the authors can describe how the AIS data were processed and the techniques used to process AIS data. Have the data been examined by looking at the path of each vessel, or at least by looking a certain number of randomly selected vessels? If yes, what are the findings?

Authors, specific comments, point 4: The theoretical range of AIS base station is about 90 km. Depending on the height of the antenna, power of the transmitter, atmospheric conditions etc. this distance may vary, finally limited by the curvature of the Earth. The potential gaps in the Baltic Sea are covered with the use of directional antennae and with floating platforms, on which AIS base stations are installed. This is done for example in the Polish Economic Zone, where PetroBaltic Beta drilling rig is equipped with a base station, expanding the coverage area significantly.

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The situation in the Baltic Sea is rather good; neighboring base stations offer a decent degree of redundancy in case of base station equipment failure. In areas of weak reception, the gaps are normally small and the STEAM program described in this manuscript was built to tolerate short interruptions in the AIS data stream. As an example, a hypothetical area of low coverage is, say 100 km. If a ship traveling through this area has a speed of 10 knots, then the time between received signals is a bit over five hours. The program would interpolate the route and emissions between two known signals over the gap.

We have incorporated several checking routines to weed out potential problem cases, like two ships using same identification numbers, sending faulty information and such. Of course, random checks are done to ensure that the program interpolates routes reliably. We do not routinely look at the path taken by every ship, but we do keep track of distances traveled by each vessel and check average speeds to determine errors. The results of this analysis are delivered to the maritime authorities, who will check the mismatched information and inform the ship's crew if errors were found in AIS data. Description of these procedures is quite lengthy and may require an additional paper to address these issues properly.

Referee 3, specific comments, point 4: Were the results of the ENTEC 2002 study compared with the results of this study? If yes, what are the findings?

Authors, specific comments, point 4: The ENTEC 2002 study reports emissions of the North Sea and the Baltic Sea combined. The ENTEC estimate of the aggregated emissions for the year 2000 is 1074 kt for NOx and 763 kt for SOx. Projections to year 2006 (assuming the SECA rules apply) are only given for total emissions for all sea areas inside the EMEP grid.

Referee 3, specific comments, point 5: What's the temporal resolution of this study? Please clarify whether the instantaneous speed and load will apply to this time period.

Authors, specific comments, point 5: STEAM interpolates emissions, fuel consumption

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and position of all ships linearly between two known position reports, if they are less than 72 hours apart. This interpolation is done in one second steps over the time difference between signals. If speed and engine load change between the two known position reports, the values from the previous position report are used in the interpolation.

A sentence describing the update rate of the position of each ship was added to Section 1.

Referee 3, specific comments, point 6: When dealing with AIS data gaps, the positions of the consecutive records should be considered. For example, if a vessel is at different locations at the beginning of the gap and the end of the gap, the vessel was moved and the activity should be included in the inventory. Please provide more detailed information on how the vessel path between data gaps was determined and how to determine whether the vessel was idling at dock or was just out of AIS coverage when there is a gap no matter greater or less than 72 hours.

Authors, specific comments, point 6: The vessel movement during a data gap has been taken into account. As an example, consider the following: Time and location of the vessel when the first message is sent are t1, lat1, lon1 Time and location of the vessel when the second message is sent are t2, lat2, lon2

The change of location (in degrees) dlat=lat2-lat1; dlon=lon2-lon1 The time difference between signals (in seconds), dtime=t2-t1 The change of location per second: dlat/dtime, dlon/dtime

There is a consistency check before any interpolation takes place. For this great circle distance between the two signals is computed and average speed is determined. If average speed of the vessel is beyond the capabilities of the ship (determined from design speed) interpolation is interrupted.

If the two signals seem consistent interpolation is done and the location and the emis-

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sions are updated each second. However, in case of speed change, the speed (and emission) from the first position report (t1, lon1, lat1) are used during the gap.

A following text was added to Section 2.2:

“The position of the vessel and its emissions are calculated each second between the two known locations after a consistency check. During the consistency check great circle distance and average speed of the vessel are calculated to determine if the vessel can really travel the distance between the two position reports. ”

Referee 3, specific comments, point 7: please explain how the numbers used here were determined or the source of these numbers.

Authors, specific comments, point 7: The numbers describing the auxiliary engine profiles were determined based on ship owner interviews. The main engineers of several ships were asked questions of different operating profiles of various kinds of ships.

Referee 3, specific comments, point 8: please provide the source of the specific fuel consumption rate used here.

Authors, specific comments, point 8: Searching the literature reveals a wide variety of values which were used in generating different emission inventories. For example, values of specific fuel consumption (SFOC) ENTEC studies (2002, 2005) range from 185 g/kWh to 213 g/kWh for diesel engines; The second IMO Greenhouse Gas study (2009) uses values ranging from 175 to 225 g/kWh depending on engine stroke type and kW. In the IMO study, a range of SFOC values are given for each of the engine type and it is stated that (Second IMO GHG study, 2009, page 185 tables A1-1 and A1-2):

“The fuel consumption in actual operation is expected to be higher than when measured in test-bed conditions. The reasons for this include: .1 the engine is not always operating optimally at its best operating point; .2 the energy content of the fuel may be lower than that of the test-bed fuel (for engines using residual fuels, this typically amounts to about 5%); .3 best SFOC values are given with 5% tolerance; and .4 engine wear, ageing and maintenance (wear of fuel injectors and injection pumps, improper settings, fouling of the turbocharger, increased resistance of oil filters, fouling of the heat exchanger and more)."

The SFOC ranges listed in Table A1-1 already show 10-20 % uncertainty in SFOC values. Even if we have used a crude estimate of 200 g/kWh as a default value if more accurate value is not available, we feel that this is a reasonable first guess which can be adjusted if necessary. The 200 g/kWh falls within the uncertainty range of most of the engine types listed in Table A1-1, except most modern two stroke engines.

We investigated the fuel consumption of new vessels with two stroke engines with the assumption that the SFOC would be 10 % lower (180 g/kWh). The effect on the inventory level for one month (Jan 2007) is 11 475 tons less fuel burned. For January the total fuel consumption would hence change from 496 640 tons to 485 165 tons. If the same is assumed for the whole year of 2007, the fuel consumption changes roughly -2 %. Note, that this assumption should also be done for four stroke engines, but the opposite direction: the SFOC value should be increased. These two changes are of opposite signs and the net effect is very likely to be close to zero.

We have added the following paragraph discussing this in Section 3.1

"The specific fuel oil consumption (SFOC) depends on engine type with two stroke engines consuming less (160-200 g/kWh) and four stroke engines slightly more (180-250 g/kWh).(IMO, 2009) Changing the default SFOC of two stroke engines to 180 g/kWh for new ships (built after 1.1.2001) decreased the monthly total fuel consumption in the Baltic Sea area by less than 2 %. Change of opposite sign will results for four stroke engines and the net effect to the results reported in this paper are likely to be small."

Referee 3, specific comments, point 8: for those vessels that operated out of the study area, how the reported fuel used within the study area was separated from fuel burned

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out of the study area?

Authors, specific comments, point 8: It was not. The AIS data was cut in a way that it only contained messages transmitted inside the study area. From shipowner reports we have no way of knowing the portion of the real fuel consumption in the Baltic Sea if the vessel leaves the Baltic Sea. We only know the total consumption of the complete voyage (and that is presented for RoPax6 in Figure 3 of the revised manuscript).

Referee 3, specific comments, point 9: please explain why the predictions with wave effects have larger difference with the reported fuel. Does that mean including wave effects in the calculation actually reduces the accuracy of the results? The effect of waves on monthly total fuel consumption which is in the order of 0-2% is small and maybe negligible. If that's the truth, perhaps it is not worth the efforts to include the wave effects in the model and/or the section describing the wave effect can be shortened or removed.

Authors, specific comments, point 9: From emission inventory point of view it is not probably necessary to include the effect of waves because the effect is likely to be small. However, if a more detailed study is made, where smaller areas are investigated and fuel consumption predictions are compared on voyage by voyage basis different conclusions appear. The current models of power prediction and the wave effects are very crude ones, for example a revision of the Kwon model exists (Kwon, The Naval Architect, March 2008, 14-16), but it has not been implemented in STEAM, yet.

To illustrate the difference of including the effect of waves and not to include it was added to the manuscript (Section 3.1 + Figure 6).

However, this is inconclusive evidence as more data for comparison is needed for different kinds of ships from the ship owners.

Referee 3, specific comments, point 10: please explain why vessel built after 2000 contribute much more to the emissions than the percentage of vessel population. Do they

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operate more and/or are they much larger than average? For figure 9, please explain why RoRo/Passenger vessels contribute much more emissions than the percentage of vessel population? And how about container vessels?

Authors, specific comments, points 10 and 11: This can be understood in terms of the distance traveled in each of the age groups and ship types.

To explain this feature, a new table and discussion of this issue was added to Section 3.3. Table 4 now shows the emission relative to vessel mileage, so the effect of distance has been removed. The conclusions made in Section 3 are still valid despite the changes made to Section 3.3.

The RoPax ships are a significant source of emissions even if the distance traveled is taken into account (Ship specific emissions are divided by the distance traveled). Effect of ship size and cargo volumes remain, however, since determination of the amount of cargo transported in each of the vessel types is a challenging task. In terms of unit emissions (g ton-1 km-1) RoPax ships are a particularly poor choice from environmental point of view.

Please also note the Supplement to this comment.

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