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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.

J.-P. Jalkanen et al.

jukka-pekka.jalkanen@fmi.fi

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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 2, general comments, point 1: Issue concerning the stack height

Authors, general comments, point 1: This approach was originally intended, but later discarded, because the lack of height data in ship particulars. Less than one percent of the responses from Lloyds register have this data field and similar observation applies to ship owner data. We agree, the information about the release height is important, as is the geometry of the funnel, temperature and exhaust flow speed, but they cannot be obtained systematically. One approach is the determination of the height of the ship from photographs if no other information source can be found, but this is a very laborious manual task. In any case, the Øresund bridge and the Danish Straits set limits both for height and draught of the largest vessels trying to enter the Baltic Sea. The clearance of the Øresund bridge is around 60 meters meaning that the stack heights would be lower than this value.

We are working with the ship owners to gather as much data of their own fleets as possible, but this approach takes time and could not be completed in the framework of this study. We are confident that the emission inventory reported in this paper can be used without the information of release height.

This issue of stack height is now mentioned in Section 2.1 (Ship properties)

Referee 2, general comments, point 2: Issue concerning error margins and the accuracy of the predicted emissions

Authors, general comments, point 2: There are at least three sources which affect the accuracy of predicted emissions: a) Emission factors themselves b) Performance prediction details c) Specific fuel oil consumption assumptions

a) Below is an example of three ships which have undergone experimental stack measurements. The experimentally determined emission factors for NOx and the result of calculation using the IMO NOx curve. These vessels do not have any emission abatement systems installed.

Ship;NOx EF (g/kWh),measured;NOx EF (g/kWh), IMO curve

General Cargo 1;12.1;13.5

RoRo1;13.5;13.0

RoRo2;13.0;13.0

The statistical analysis of the data set behind the IMO NOx curve lists the 95 % confidence intervals for emission factors of slow and medium speed diesel engines. (International Maritime Organization, Study of Greenhouse Gas Emissions from ships, study by Marintek, Carnegie Mellon University, Det Norske Veritas and Center of Economic Analysis, Appendix A, 2000).

The emission factors described in STEAM treats them as independent of load. Strictly speaking this is not true, since emission factors (g/kWh) are dependent on engine load and they may increase if the engine is operated outside the optimum load range. This is particularly the case in harbor areas during port maneuvers.

b) Even if the emission factors would be known accurately, the total emission is a function of engine load. If the engine power predictions based on instantaneous speed are inaccurate it immediately shows as poor performance of the model. We have compared the predicted engine loads with the ship owner reports and evaluated the performance of the model.

Figure 1 presents the comparison of power profiles of a 60 000 GT RoPax ship during its voyage from Stockholm, Sweden to Helsinki, Finland. As can be seen from Figure 1, predictions are in good agreement with the numbers obtained directly from the engine room. Since the predicted instantaneous power is based on ship speed, no emissions occur in cases where ship is not moving, even if the main engines are still running. This is the case during very short harbor visits (Mariehamn harbor).

c) The default values used for fuel consumption in our study is 200 g/kWh. This value is used if no better estimate of the fuel consumption is available. The program allows for

engine specific consumption values, which can be obtained from the ship owners. The engine manufacturer reports are normally measured using standardized test cycles and may not reflect the real world consumption during ship operation. Exactly the same applies to car engines; manufacturers consistently report fuel consumption which is based on standard test cycles and are difficult to match with realistic driving conditions. The result is that real consumption can be higher than what is the “official” value.

True, one could take average specific fuel consumption for two stroke engines (slightly lower than our estimate) and four stroke engines (slightly higher than our estimate) from literature, but to our opinion this does not necessarily improve the situation unless the values are significantly different, like for example for turbine engines, from current estimates. In our opinion, the 200 g/kWh is a reasonable default value for fuel consumption, unless more accurate information is obtained from the ship owners.

A paragraph describing the uncertainty of emission factors was added to Section 2.

Referee 2, general comments, point 3: It is for example not clear if the model could be globally applied if AIS signals can only be picked up 90 km from the coast.

Authors, general comments, point 3: This is a good point, but simple answer to this issue does not exist.

Signals can be picked about 90 km off the coast and full coverage can be expected on sea areas, which are sufficiently small, like the Baltic Sea. Areas further away from shore require special actions, like floating platforms on which AIS base stations would be installed. Already there is an example of this in the Baltic Sea, where PetroBaltic Beta drilling rig is equipped with an AIS base station improving the AIS coverage in the Polish Economic Zone. Similar approach may be used for example for wind power stations/platforms extending the coverage of AIS significantly. For sea regions like the Atlantic Oceans this approach would be very difficult. For that purpose a satellite based AIS base station network would have to be used. To our knowledge, there are at least three commercial operators which are offering this kind of service. Access to global

AIS is available, albeit the price of this may be very high.

A paragraph describing the coverage of the AIS system was added to Section 2.2

Referee 2, general comments, point 4: The uncertainty of the emission factors is also not discussed nor is a persepective for other important emissions like PM (incl. soot), NMVOC or CO given. The uncertainties of the emissions themselves might be large and in sharp contrast to the accuracy of the activity data presented here.

Authors, general comments, point 4: A paragraph discussing the uncertainty of emission factors has been added to Section 2.

The inclusion of other pollutants has been left for future work. Before adding more pollutants a method of estimating the engine load must be included. This is very much an issue of emissions like PM and CO, emission factors of which are strongly dependent on engine load. Of course one could bluntly just use a default constant emission factor for PM without dividing the total PM further into components and use it just like the NOx emission factor, but this approach, to our mind, is a bit crude and we are certain that a more accurate approach is possible.

In case of two-stroke engines estimating the engine load is trivial since only one main engine is used, but the cases where more than one main engine exists, a method for estimating the engine load and the number of engines in use would have to be developed. We are currently working on this issue and add PM, CO and NMVOC to the model soon.

To clarify the choice of pollutants included in our study, we have added a paragraph addressing the reasons for not including PM and CO in our study.

Referee 2, general comments, point 5: The attempt to use a wave model and correct for the additional fuel use caused by waves is extensively described and certainly costly to implement. In the end it is not used here or the effect are described to be of minor importance in almost all cases. This is an interesting result and it would be good to give

advice to others whether waves need to be considered in ship emission inventories or not.

Authors, general comments, point 5: Discussion of this topic was added to Section 3.1

Referee 2, Specific comments, point 1: Which time frame underlies the accuracy of 6 %. I assume it's an annual average but this should be stated. It should also be said more clearly from the beginning that data for the complete year 2007 is presented.

Authors, Specific comments, point 1: These have been added to Abstract section

Referee 2, specific comments, point 2: "provided that AIS data are available": the reader cannot judge what this limitation means. Is the data freely accessible? What about regions far from the coast? This needs to be discussed and not only stated.

Authors, specific comments, point 2: This is now discussed in Section 2.2

Referee 2, specific comments, point 3: "60000 premature deaths": in which time?

Authors, specific comments, point 4: This sentence has been modified to illustrate the number of annual premature deaths.

Referee 2, specific comments, point 5: Here it is said that a complete coverage with data from the AIS will not be possible in most regions. This contradicts the potentially global use that is described on page 15343, line 21.

Authors, specific comments, point 5: This sentence has been modified to clarify the possibilities of expanding AIS coverage to open sea areas.

Referee 2, specific comments, point 6: It is hard to see where a temporal resolution of one second would be needed. Additionally this resolution only holds for the position and the speed of the ship, so in my opinion this statement is misleading. In the real world, the ship emissions at the stack will certainly also fluctuate on a level of seconds but this cannot be reflected in the emission inventory and therefore the authors should not pretend an accuracy that cannot be reached with temporally constant emission factors. It is far more important that the position of the ships can be determined very accurately.

Authors, specific comments, point 6: This sentence has been modified.

Referee 2, specific comments, point 7: As far as I understand the system might also be applied in other regions of the world but not globally in a sense of everywhere around the globe. It would be interesting to know if the AIS data from other regions than the Baltic Sea would be available.

Authors, specific comments, point 7: Yes and no. The model can be applied globally, if one had access to a satellite based AIS network. This option is currently available, but the price of annual subscription is very high. AIS transmissions are not encrypted in any way. Anyone with a VHF antenna and the ability to listen specific frequencies can receive them.

A totally different thing is the access to regional AIS archives, which normally require a political decision of member states of that specific region. For example, the access to the Baltic Sea AIS data required unanimous support from all riparian countries. On national level, access to domestic AIS network can usually be negotiated with local maritime authorities. On local scale, anyone can set up a base station and save AIS data in the surrounding area.

Referee 2, specific comments, point 8: what is a "small craft"? Smaller than what, please be more specific.

Authors, specific comments, point 8: A short description of “small craft” was added to Section 2.2.

The number of small craft can be large especially during summer months. This trend can be seen over several years, so it is not restricted to 2007 and it is likely to continue since the class B AIS equipment is becoming more popular among owners of small craft. Class A device is for big ships, while class B device is designed to be simpler,

cheaper and suit the needs of leisure boats better than a class A device.

In the cases where the AIS transmissions do not include the IMO registry number, MMSI code is used for vessel identification. We have compared the data from AIS transmissions from small craft against national vessel registries. Unfortunately, this is a laborious manual task since at least in case of Finland; it cannot be automated because not all records are in electronic format. Small craft may include various Search & Rescue vessels, tugboats, pilot vessels, small yachts and so on. Most of them can be identified, some cannot.

The transmissions may still include physical dimensions. If MMSI code and the vessel name are known, then a search using national vessel registries can be done. Secondary means of identification is the MMSI code. The code is part of the Digital Selective Calling system of the vessel and it is granted by national radio authorities. Comparing the MMSI code in AIS and the list of granted MMSI codes, the vessel may be identified. One should note that the IMO registry number is specific for each ship and it cannot be changed or reassigned. This is not the case with MMSI code and this is the reason why ships cannot be identified reliably using just the MMSI code. The MMSI code also changes if the flag state of the ship is changed and a new radio license is applied.

If physical dimensions are transmitted in AIS they are used in emission calculations. If not, then averages from the smallest ship class are used for ship particulars. One should note that the information of the engines can never be obtained from AIS messages and one must use some average value for main and auxiliary engine power for these cases. This is the last resort option of the program and only used for cases where insufficient data exists.

The assumption of using the “small craft” type for vessels which cannot be found from Lloyds register may not be that far from the truth and it was designed to give a baseline estimate of emissions. This way, problems in ship identification may contribute to emissions in a way that would underestimate the total emitted amount of pollutants.

Referee 2, specific comments, point 9: Can you comment on the uncertainty of these emission factors? Have there been comparisons to real measurements at the stack or behind the ship?

Authors, specific comments, point 9: Uncertainty of emissions can consist of the following: a) For NOx, the IMO curve and change of emission factors as a function of engine load b) For SOx, from specific fuel oil consumption and c) the type of fuel used since SOx emissions are based on the sulphur content of the fuel

NOx: We have several cases where the ship owner has experimentally determined emission factors for his/her fleet. There is an example given in Referee 2 general comments (Point 2) which illustrates the applicability of NOx emission factors obtained from the IMO NOx curve. We would like to stress that if experimentally determined emission factors are known, then they are used in STEAM emission estimates, otherwise the NOx emission factor is based on the engine rpm and the IMO NOx curve.

SOx: The emission depends on the specific fuel oil consumption and the fuel sulphur content. By default, STEAM uses 200 g/kWh specific fuel oil consumption for all main and auxiliary engines. If more accurate information is available from the ship owners, then these values are used. One could go further and separate the fuel consumption of four stroke engines to slightly higher than 200 g/kWh and the fuel consumption of two stroke engines slightly lower, but to our mind the 200 g/kWh should be fairly reasonable first estimate of the fuel consumption.

In the case of turbine engines, when the specific fuel oil consumption is markedly different from diesel engines, larger differences may appear. Turbine engines should be handled separately, but the number of ships using turbines in the Baltic Sea is limited.

If the fuel type is unknown, the default sulphur content of 1.5 mass-% of sulphur is

assumed according to the current rules for the Baltic Sea SOx Emission Control Area (SECA) regulations of the IMO. For auxiliary engine fuel, a sulphur content of 0.5 mass-% is used. These assumptions apply to cases when no ship owner report of the fuel used exists.

Direct stack measurements to determine the accuracy of the model will start on Q1/2010. Comparisons to airborne flue gas measurements have not done been done yet, but may become possible in the future.

Referee 2, specific comments, point 10: Please give a formula how the emissions of SO2 and CO2 are calculated.

Authors, specific comments, point 10: The formulation for calculating the emission factors of SOx and CO2 is described in Appendix 1. A reference to Appendix 1 is made in Section 2.2

Referee 2, specific comments, point 10: How often is the IMO curve not used? How often are measured emission levels available?

Authors, specific comments, point 10: Of the 20 000 ships in the STEAM database, stack measurements are available for about 0.3 % of the total number. Emission abatement techniques are known to be installed to about 0.7 % of the vessels. One should note that not all of the 20 000 ships operate in the Baltic Sea area.

Referee 2, specific comments, point 11: "2.0.1": strange numbering, is most likely wrong.

Authors, specific comments, point 11: This has been corrected

Referee 2, specific comments, point 12: So how do you determine k? This is not described.

Authors, specific comments, point 12: Description of how k is calculated was added to Section 2.3.1.

Referee 2, specific comments, point 13: " ... if the shipowner has made this data available." Again a limitation that cannot be judged by the reader if it is of importance or not. How often is data from the ship owners available? I would assume this is the minority of cases.

Authors, specific comments, point 13: Agreed, this is a minority of cases. Currently we are working with ship owners from Finland and Estonia and the maritime authorities of the Baltic Sea countries, but we are constantly working to include as much experimental data as possible.

A statement highlighting this has been added to Section 2.2.1

Referee 2, specific comments, point 14: How many ships are RoPax vessels? Is it enough to validate the dataset with these 6 ships?

Authors, specific comments, point 14: Agreed, the validation should be done against maximum possible number of ships in each ship type. RoPaxes were selected as an example because most detailed data for comparison was obtained from the ship owners. RoPax class is also a very complicated case, since wildly different kinds of ships fall into this class and very often more than one main engine is installed and used.

Referee 2, specific comments, point 15: " ... if the shipowner has made this data available." Again a limitation that cannot be judged by the reader if it is of importance or not. How often is data from the ship owners available? I would assume this is the minority of cases

Authors, specific comments, point 15: The following sentence has been added to Section 2.3.2: “Currently these cases constitute less than 1 % of all the ships in the Baltic Sea area.”

Referee 2, specific comments, point 16: I would like to see a graphic for the directional part of the speed penalty.

Authors, specific comments, point 16: We implemented the method described by Townsin et al (RINA Transactions, 1993, 135), where the total penalty comes in two parts; the first is the percentage of speed lost due to waves and the second part the directional component, which varies between zero and one. Beaufort number 8 matches the situation on Dec 22nd 2004, when the all time record (7.7 m) in significant wave height was recorded during storm north of the island of Gotland, Sweden.

A new figure showing the directional dependence of the speed penalty and a paragraph discussing this issue were added to Section 2.3.3 (Included as Fig 2 in this comment)

Referee 2, specific comments, point 17: Strange symbol for the displacement volume.

Authors, specific comments, point 17: We have tried to follow the notation used in the following works:

Schneekluth and Bertam, “Ship Design fir Efficiency and Economy”, Butterworth-Heinemann, Oxford UK 1998

Tupper, “Introduction to Naval Architecture”, 4th edition, Elsevier, Oxford, UK 2004

Gillmer and Johnson “Introduction to Naval Architecture”, United States Naval Institute, Annapolis, USA 1982.

Referee 2, specific comments, point 18: What is the arguemnt to restrict the speed penalty?

Authors, specific comments, point 18: The relative speed reduction in the paper of Townsin et al is restricted to 25%. Also the volume of displacement of the smallest vessel in the paper of Townsin et al is over 50 000 m3. Since the relative speed reduction is dependent on the vessel size, and also very small vessels are equipped with AIS, the use of a very high speed penalty is clearly an extrapolation of the results of Townsin et al. On the other hand, the influence of waves was found to be rather small, at least for the time interval investigated, and omitting the restriction would have yielded similar results.

The motivation to restrict the wave penalty is now included in Section 2.2.1

Referee 2, specific comments, point 19: How many (percentage) measured emission factors are in the data base? How much do they deviate from formula (1)?

Authors, specific comments, point 19: Please, see Authors' response to Referee 2, specific comments, points 2, 9 and 10.

Referee 2, specific comments, point 20: How often (percentage) are the average values used?

Authors, specific comments, point 20: Average values are in issue for the ships which do not have an IMO number and are not included in the Lloyds register database. One can search Lloyds register with an MMSI code, but quite often this approach leads to no better results. The number of small vessels for which any of the average values is applied was for example 618 out of 3800 in January 2007. Note that for 3182 out of the 3800 cases IMO number can be used for identifying the ship reliably. For 172 cases the only information received is the MMSI code and for the rest 446 cases report both vessel name and the MMSI code. Currently 618 cases (16.3 %) are treated as small emission sources as not to overestimate the emission levels in the Baltic Sea area. Note, that these numbers represent the cases where any of the required data fields were augmented with averages. In reality, various degrees of vessel data gaps exist, ranging from complete failure to find any of the data from Lloyds register to lacking description of a single data field.

Referee 2, specific comments, point 21: if the share of small crafts (unidentified vessels) is at a maxiumum 10 % in summer, why is the number of vessels with unknown age 23 % of all vessels in Fig. 8?

Authors, specific comments, point 21: The "unidentified" label is used for ships which only transmit the MMSI code without any other vessel related information besides the position report. The previous comment (point 20) addresses shows the numbers for

January 2007: 172 vessels would be designated as "unidentified" (172/3800, 4.5 %) while problems of finding build year information would be encountered in 618 cases (16.3 %).

If the vessel transmits both name and MMSI code it can be identified. However, in case of small craft build year may not be readily available. The data obtained from Lloyds register is not perfect, either. It does not necessarily include all the required fields in all the cases. We have tried to complement the STEAM database from other sources, but this will take time because the process is manual.

Referee 2, specific comments, point 22: fuel oil consumption of 200 g/kWh is used by default for all engines". Other authors (e.g. Endresen, 2003) differentiate between different speeds. Why is this not done here? This gives the reader the impression that the activity data is handled in very high detail while the emission factors are rough estimates. You should try to avoid this.

Authors, specific comments, point 22: Please see Referee 2, specific comments, point 9 and Referee 2, general comments, point 2. As long as the predicted kilowatts and the resulting fuel consumption predictions agree with the ship owner reports, we feel that the 200 g/kWh estimate is a reasonable default value. The error arising from the 200 g/kWh is very likely smaller than the complete neglect of auxiliary engine usage in some previous studies.

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 (Second IMO GHG study, 2009, page 185 tables A1-1 and A1-2):

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 a 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 (2001-2009) 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 (January 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 percent. 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 small.

Test runs to ascertain the influence of stroke specific SFOC were conducted for January 2007 AIS data. The following paragraph was added to Section 3.1

“The specific fuel oil consumption (SFOC) depends on the engine type; two-stroke engines consume 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 result for four-stroke engines and the net effect to the results reported in this study is likely to be negligible.”

Referee 2, specific comments, point 23: "In the following ...". The sentence is misplaced here.

Authors, specific comments, point 22: This sentence has been moved to the end of Section 3.1

Referee 2, specific comments, point 23: This paragraph as well as Fig. 2 are not necessary and should be deleted.

Authors, specific comments, point 23: These were removed from the manuscript.

Referee 2, specific comments, point 24: "kW value" is colloquial.

Authors, specific comments, point 24: This has been corrected

Referee 2, specific comments, point 25: The inclusion of wave effects leads to slightly worse agreement (in this single case) and the overall effect is of minor importance. This should be staed more clearly, it could also be said here that the following calculations neglect the effect of waves.

Authors, specific comments, point 25: The effect of waves may be of small significance on the inventory level, but as the scope of the study is shifted towards single ships it becomes significant. Note, that the work described in this paper is not intended just to serve the data needs of pollutant transport models, but to provide supporting information for decision making.

To illustrate the effect of waves better, Figure 6 was added to the revised manuscript describing the effect during a single voyage, showing the hourly fuel consumption with and without waves. The predicted fuel consumption is now compared with the ship owner data from this voyage. We agree with the referee that significantly more ship owner data is needed for conclusive judgment regarding the effect of waves and this is stated in Section 3.1 along with the statement that all consecutive results are computed neglecting the effect of waves. Figure 6 is included in this comment as Figure 3.

Referee 2, specific comments, point 25: Is Lloyd’s ship register freely accessible in the www?

Authors, specific comments, point 25: No. Lloyds register is a commercial service and a subscription is needed to gain access to the data.

Referee 2, specific comments, point 26: It would also be interesting to know the average power of the ships in the different categories because this should be directly related to the emissions. It is quite surprising that RoRo/Passenger ships have so high emissions despite their low share in total number.

Authors, specific comments, point 26: To illustrate the ship types and their emissions more clearly, a Table 4 has been added to Section 3.3 of the revised manuscript showing the relative emissions taking the vessel mileage into account. We agree with Referee 1 that this addition is useful, since different ships travel different distances and emissions should be related to the distance each ship has traveled during the study period. The average values for main engine power are shown in a table below (data from January 2007).

Ship type Average ME power (kW)

Cruise ship 25418

Icebreaker 15026

RoPax cargo 14601

Crude oil tanker 11953

Container ship 11814

RoRo cargo 11059

Vehicle carrier 10656

Bulk cargo 7329

Refrigerated cargo 6888

Chemical tanker 5358

Supply ship 4819

LPG tanker 4617

Oil product tanker 4306

Fishing vessel 3941

Police, military 3277

Tug 2532

General cargo 2204

Other 1996

Search and rescue 1980

Passenger ship 1484

Barge 1343

Yacht 1145

Dredger 925

Ferry boat 662

Referee 2, specific comments, point 27: "Pushing engines to their limits rapidly increases the fuel consumption ...": I understood from page 15350, line 22, that fuel consumption depends only on installed power (or on used power?). How do you consider the effect of a tight schedule in your model?

Authors, specific comments, point 27: As the instantaneous power is estimated as a cube of speed, the power demand increases sharply if the design speed is reached or exceeded. Ships with a tight schedule travel very close to their design speed.

Referee 2, specific comments, point 28: " .. the electricity ... cannot be obtained this way." What is the implication? What do you want to say with this statement?

Authors, specific comments, point 28: Waste heat can be recovered and used for example heating the service water. Heat is a byproduct, use of which can be organized rather easily, but electricity is needed to run air conditioning or cargo cooling. While it is possible to use steam and turbines for generating electricity from exhaust heat, it is rarer than waste heat recovery systems. Our thought in this was that waste heat can be utilized, but for cooling extra electricity is needed and that is generated by the auxiliary engines.

This assumption has been clarified in Section 3.3 by adding a sentence: "Extra electricity for the air conditioning and/or cargo cooling is usually generated by the auxiliary engines or shaft generators."

Referee 2, specific comments, point 29: Why is this only given for NOx? You should also explain why the distribution into flag states is of interest.

Authors, specific comments, point 29: This distribution is given for NOx because this was the primary concern when the program was constructed. Since the Baltic Sea is already a SOx Emission Control Area and efficient rules for reducing sulphur exist, the focus of interest of stakeholders is shifted towards NOx, for which similar restrictions are currently planned.

To our knowledge, only speculations existed of the emissions shares of different flags in the Baltic Sea area. To investigate this in more detail it was decided to divide the emissions according to flag state and see what the results look like.

The following text has been added to Section 3.3 "The flag state distribution of emissions has been mentioned as one of the mechanisms of emissions trading, but this may lead to a tonnage shifts (IMO, 2009) towards less rigorously regulated flags unless restirtions were applied globally."

Referee 2, specific comments, point 29: "Clearly, ..." Is this meant as excuse? What about Poland and the Baltic States?

Authors, specific comments, point 29: The statement illustrates the fact that from the logistics point of view, Finland and Sweden are islands. Sure, land route from Finland exists through Russian Federation, but most of the export is done by sea. For Poland

and the Baltic states, other options are available.

This part of the text was modified

Referee 2, specific comments, point 30: The vertical is also a spatial dimension that should not be left out if you claim an extremely high resolution of your data.

Authors, specific comments, point 30: True. The following sentence was added to Section 4. "The information regarding the stack height is not taken into account, yet, which may be significant in estimating the long range transport of emissions arising from shipping."

Referee 2, specific comments, point 31: It would be nice to give an estimate on the overall uncertainty of the emissions and state what the largest uncertainties are.

Authors, specific comments, point 31: This can only be done for cases where enough data exists for comparison. We aimed the model to yield a lower limit estimate of shipping emissions by downplaying various uncertainties in a way which would lead to smaller emissions than in reality. Large sources of uncertainty concerns the non-AIS traffic. There is no central database of vessel movements or an easy way to account for this traffic. We are confident that the vessels designated as "unidentified" and small, are that also in reality. Of course, exceptions to this rule can occur, but it is more probable that these emission sources are small than large. Obviously more work is needed regarding the auxiliary engine profiles and more pollutants will be added when more information regarding these issues accumulates over time.

Discussion of model uncertainties has been added to Sections 2 and 4.

Referee 2, specific comments, point 31: "... provided that the AIS data ...": Again a limitation of which the reader does not know what it means. How realistic is it to use the model somewhere else?

Authors, specific comments, point 31: It is very realistic. To determine the availability of AIS data one can consider these cases:

a) Local scale, about 90 km radius from a single base station. b) National scale, the AIS base station network of a single country c) Regional scale, for example the Baltic Sea, North Sea etc. d) Global scale, commercial operators for relaying the satellite AIS data exist

Case a) The AIS data is completely freely available. Anyone with a VHF radio antenna can receive the transmissions when tuned to proper frequency. The position reports can be saved to a hard disk or transmitted through a computer network for analysis.

Case b) The use of a national AIS network usually requires that an agreement between the local maritime authorities (whoever is maintaining the national network) and the institute asking for access is signed. Normally this should not be a problem.

Cases c) and d) This is where negotiations for access to AIS data can get tricky. For example in the case of the Baltic Sea, representatives of all the Baltic Sea countries had to provide unanimous support for access to the data. I would imagine similar approach would be required in the case of other sea regions since it is unlikely that an AIS network of a single country would cover large enough area. Both regional and global options can be covered by commercial data providers if cooperation with authorities of different countries fails.

If global coverage is wanted, commercial operators are the only providers of the service. There are currently at least three separate enterprises offering satellite based AIS solutions. For example Lloyds sells access to satellite based AIS network data advertising complete global coverage. The price of this data is very likely to be high, but hourly update of all the vessel movements globally can be achieved according to their representatives.

The following paragraph was added to Section 2.2 of the manuscript: "The data can be freely received with a VHF antenna, since it is not encrypted. However, the use of a national AIS base station network data may require an agreement with the national maritime administration. The use of AIS for extensive sea regions may involve

negotiations with authorities in many countries, but the data can also be accessed commercially. Global coverage can only be expected from commercial data providers utilizing a satellite-based AIS network."

Authors, Technical corrections suggested by Referee 2: These were corrected. The reason for different height of SOx and CO2 bars is that some ships voluntarily use fuel, which has less sulphur than what is the maximum allowed (1.5 mass-%). This is now explained in the text, Section 3.3.

Please also note the Supplement to this comment.

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

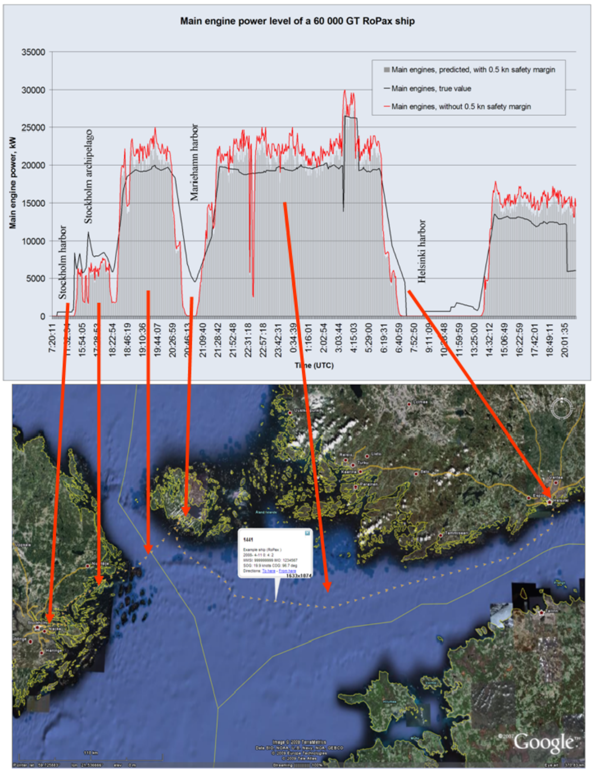

Fig. 1. The actual and predicted engine power profiles obtained onboard a RoPax ship during its voyage.

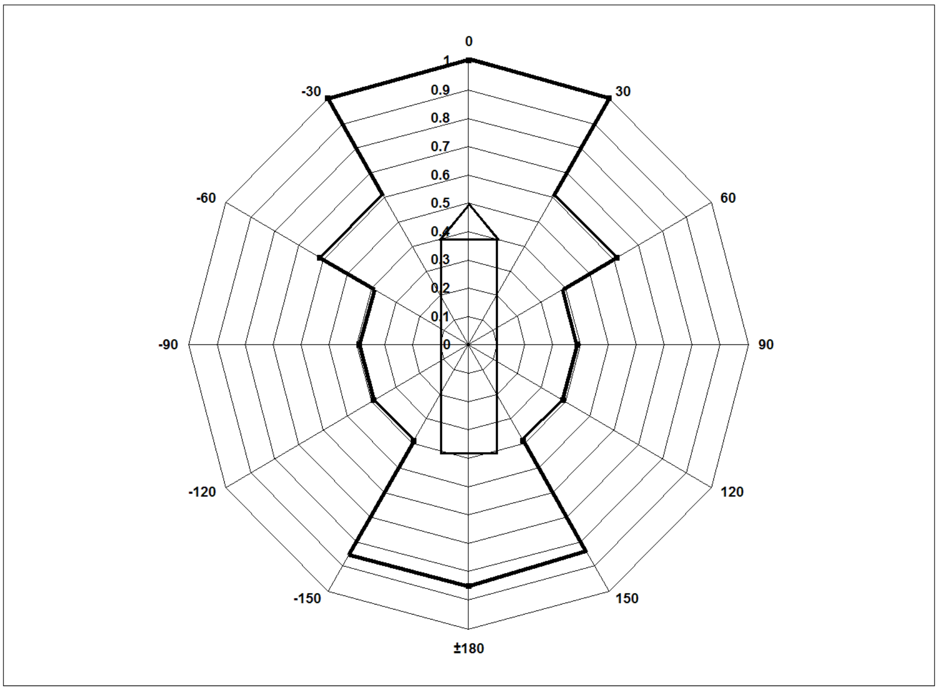

Fig. 2. The directional part of the wave penalty (Beaufort number 8)

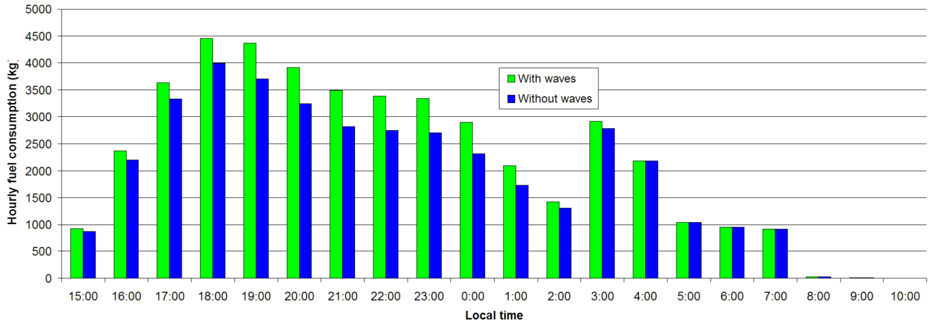

Fig. 3. Hourly fuel consumption of the main engines of a RoPax with and without the effect of waves.