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Interactive Comment

# *Interactive comment on* "The impact of shipping emissions on air pollution in the Greater North Sea region – Part 1: Current emissions and concentrations" *by* A. Aulinger et al.

**A. Aulinger et al.**

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Genaral comments:

R: First, this manuscript describes a newly developed ship emission model, but falls short on details. Emission factors are reported only for BC, but for all other species the reader is referred to MSc thesis of Zeretzke (2013). I could not track down this reference and I would need to see how the authors handle the load dependency of the emission factors in case of other pollutants, since authors use this as justification to current work. I would suggest an addition of a new section, which describes which

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emission factors have been used and how the engine load and fuel type dependency is applied.

A: Initially, we planned a third part of the publication series to describe these in detail. Instead, we extended the model description section by the emission factor functions ( section 2.4) and provide the formulae in an appendix.

R: Second, the authors state that emissions from ships in port areas are not included in the current manuscript. I find this a serious shortcoming because it makes the comparisons of consecutive modeling work to air quality measurements difficult. Since the contribution from port areas is included in the measurements, it should also be included on the modeling side.

A: More precisely, we didn't include ships moving slower than 2kn or ships at berth. We don't think that this lack has a decisive influence on the conclusions of the paper about the influence of shipping emissions in the North Sea region as a whole. Port emissions are essential for assessing local effects. They become gradually less relevant the bigger the influenced region is. As ports cover one – or at maximum two – grid cells, they have the characteristics of point sources. According to Hammingh et al. port emissions account for ca. 10% of the NOx emissions in the North Sea, half of which is emitted from ships at berth. Our own estimations amount to 6.4% taking into account, however, only the five biggest North Sea ports. We chose background station measurements for the model evaluation because we wanted to assess the model's ability to simulate regional effects of emissions from the shipping sector – instead of small scale local effects. There was no doubt that the model resolution of the CTM would be to coarse for simulating small scale effects. Of course, including port emissions would enhance the emission inventory and probably also the comparability of the concentration simulations to measurements. Concerning our simplification of the treatment of auxiliary engines and neglecting the fact that the not-needed engines of vessels with multiple engines are switched off to operate the remaining ones at the optimum load: We carried out some sensitivity analyses and quantified the error that is introduced into



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the emission estimates by our simplifications.

R: Third, a new model is introduced but its performance is not evaluated against any kind of experimental data. Or is it done in Zeretzke thesis? This reference seems essential to this manuscript, but I cannot track it down. I found a reference to Vinken et al (2014), which links this work to satellite observations of NOx, but I would have liked to see fuel consumption or stack measurement comparison to judge whether measured emission are correctly reproduced.

A: Zeretzke carried out one stack measurement at one cruise ship which we are unfortunately not allowed to publish. Stack measurements could reveal the accuracy of emission calculation for one or a few exemplary vessels. As the main goal of this study was to show influences on air pollution levels, the experimental data we compared our simulations with are measurements of pollutant concentrations in the atmosphere because the main outcome of our combined model approach (emissions and chemical transport) is concentration levels of air pollutants. On the one hand, it is true that we didn't evaluate modeled emissions against measurements at the stack of vessels in operation. On the other hand, the emission factor functions are developed from over 400 test bed measurements. This is the reason why we regard our emission factor functions as justified. As already mentioned above, we will describe the development of the emission factor functions in detail in the revision.

Specific comments:

a) Page 11279, L12-15. I would say that EU sulphur directive is also relevant here, because it goes beyond the IMO Marpol regulations.

A: The EU sulphur directive is mentioned now in the introduction.

b) Page 11279, L25: I would be careful with statements like "state-of-the-art" which sound like marketing speech.

A: This term was replaced by "bottom-up"

c) Page 11281, L1-24: You are missing the third piece of the puzzle. The first is AIS data, the second is the emission model and the third is the technical data of ships. The authors are using vessel specific activity data, but do not mention the tech data here. This should be included in this description.

A: We added a sentence in this introductory part of section 2: ”The engine characteristics needed to calculate the engine loads were taken from a data base acquired from IHS Fairplay combined with one from GL”. In detail, it is described in section 2.3.

d) Page 11283, L12-13: “...it was made sure that the interpolated route did not cross solid ground”. I would like to read some more of this part. Linear interpolation between points inevitably leads to vessel trajectories which go over land. What methodology was used to allocate the vessel traffic to water areas?

A: We replaced the sentence “At the same time, it was made sure that the interpolated route did not cross solid ground” by “Several routes were predefined that ships would use to circumnavigate certain capes or coastlines. In case an interpolated track point would be positioned on land it was moved to the appropriate predefined route.”

e) Page 11283, Lines 5-8: Are you saying that you remove data points, which can be reached by the ship (speed required to cover the distance are below the design speed), but do not “fit the speed pattern”? What time interval is used for this? One hour? Changing speed can occur frequently in geographically complicated water areas like the Elbe river and Hamburg harbor entrance.

A: There was a typo. Instead of “These signals and the therein contained track ...” it must read “These signals and the therein contained track point ...”. Thus, we deleted only single track points, not the whole track. It is true that sailing in complex terrain will cause frequent speed changes, but rather on the lower end of the vessel’s speed. The replacement pattern applies rather to implausibly high speeds. To illustrate what we mean by an implausible movement we inserted “For example: A ship could jump from the German coast to Norway and back.”

f) Page 11284, L5-6: The discussion regarding the linking IMO and MMSI together. How do you treat flag changes in this regard? Ships are sold and their flag registry changed frequently. In that case, the same vessel can have at least two MMSI numbers during a year.

A: Wrong MMSI numbers because of fleet changes were not treated at all. On the other hand, IMO numbers that were found with this method were around 1% of the missing numbers.

g) Page 11284, L7-12: The coverage of auxiliary engine data is quite low in IHS data. GL data is better in this regard, but it does not cover the global fleet in its entirety. What data is used to determine the installed aux engine power? Have you tried other sources than IHS, GL?

A: Missing auxiliary engine power like any other missing vessel characteristics data were taken from the median tables as explained in section 2.3. All these tables are in the new appendix.

h) Page 11284, L24-25: IMO number can be valid, but the commercial IHS databases may have some lag when introducing newly built vessels. Have you tried other sources (yard hull lists, owner data etc)

A: We did not examine other sources than IHS and GL for ship characteristics.

i) Page 11285, L2-4: The discussion regarding Black Carbon. I noticed that you have listed both BC and POA as emission species. How can you be sure that double counting does not take place? It is usual that organic part of carbonaceous aerosols contain species which are also present in BC absorbance measurements? See for example Andreae and Gelencer, 2006, 6, 3131-3148 or the work of Dan Lack and Andreas Petzold.

A: The analytical method used for the measurements, the sequential thermal analysis, ensured a maximum separation of these two species. It is explained in the text now.



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j) Page 11285, L8-9: You should not neglect the emissions from ships in port areas. This will inevitably distort the results, especially when you are using the emissions as input to CTM work and then assessing the quality of modeling with AQ measurements. You will never obtain a match with the measurements if you neglect part of the emissions.

A: We extrapolated the known NOx emissions in the port of Antwerp to the five biggest North Sea ports. Based on this, we estimated the port emissions to 6.4% of the emissions on the North Sea. We added this estimation to the section 2.5. From our point of view, this is not negligible but not decisive, either. See also our answer to the general comments.

k) Page 11285, L16: "For auxiliary engines the load for moving ships was kept constant at 0.3". How do you come up with this engine load level? It is usual that ships have more than one auxiliary engine and only some of them are used. In these cases individual engines are run with higher loads than 0.3. Also, the need for auxiliary engine power varies a lot according to ship type and power transmission.

A: This value was found in an ENTEC report. We will of course add the reference. Whall et al. 2002 proposed in the report "Quantification of emissions from ships associated with ship movements between ports in the European Community" to keep the load of auxiliary engines of ships while sailing the open sea at 30%. In addition, they stated that the share of emissions from auxiliary engines while the ship is sailing is quite low so that inaccuracies introduced by this simplification with regards to the total ships emissions is relatively small. We carried out a sensitivity run for one week (21st) where we set the emissions from all main engines to zero. This run revealed that the contribution of auxiliary engines to the total fuel consumption of all ships at sea is ca. 13% in our model. Thus, if the load of auxiliary engines were for example assumed to be 40% instead of 30% the total fuel consumption would rise by ca. 4%. This lies clearly within the error margin of 10% for the SO2 emission factor and 20% for the NOx emission factor, also estimated by Whall et al. 2002.



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l)Page 11285-11286: The discussion of engine load evaluation and the assumptions used. This will lead to problems, for sure. First, the authors state that engine load is valid only 0.25-1.0 range. To my mind, the cubic relationship with speed will result to 0.25 engine load with relatively high speeds. Let us assume a vessel has design speed of 21 knots. The 0.25 load level will occur already at speeds lower than 13 knots, if you use the cubic dependency. I would say that this methodology only works with ships sailing at or near cruise speeds in high seas. It may not be applicable to the North Sea fleet, because there is a sizeable fleet with four stroke engines which do not follow this dependency. It is more likely that unnecessary engines are switched off to keep the load levels reasonable even at lower speeds.

A: This point is probably important for navigating in estuaries. However, according to some checks we did, we don't think this has much influence on an inventory for the entire North Sea where ships mostly sail the open Sea: We evaluated at first our data base to quantify the error introduced in the emission inventory by not considering the behavior of 4-stroke engines. Indeed, about half of the fleet cruising the North Sea was equipped with 4-stroke engines. However, more than 90% of these have relative small engines with total power less than 10000 kW. Most of these vessels have a design speed of 15kn or less. The mid of the frequency distribution is at 12.5kn, the speed corresponding to 0.25 load is about 7.9. We then investigated the AIS signals of all 4-stroke engine ships with a design speed between 10 and 15kn. About 18% of the movements of these vessels correspond to low engine loads according to the assumptions described above. We now assume a 4-stroke engine with 4 engines and 10000 kW power and use the function for ships < 15000kW to calculate the fuel consumption factor. The fuel consumption factor is then 199.9 g/kwh for 0.25 load and 185.7 g/kwh for 0.75 load. It would be most reasonable to run 2 engines at 0.5 load and switch of the other ones. The fuel consumption factor for 0.5 load is 189.8. The difference is 5%. If we take into account that the ratio of movements where low load situations occur is 18%, the reduction for 4-stroke engines with MCR of 10000 kW or below is 0.9%. According to table 2, the share of vessels with <10000 kW MCR in the total fuel consumption in 2011 is 28%. (This includes however also non-4-stroke engines). Summarizing all these considerations, we estimate the reduction in fuel consumption for our ship emission inventory to be 0.25% (28*0.009) if 4-stroke engines were run in an optimized mode at low-load conditions. The same considerations apply probably to emissions.

m) Page 11286, L1-3: The discussion of cases where speeds observed are higher than speeds reported in IHS data. It seems that the authors have not considered the contribution from external effects, like movement of water because of river outflow, sea currents, tide etc. Instead, they modify the speed entry of their ship tech data to match the observed maximum. This is not the way, because you are actually altering the hydrodynamic performance of the vessels, which is not correct. You will change the entire speed/powering curve with this trick and the change becomes severe if vessel travels at high speed because of the cubic speed dependency. The power curve increases sharply near the design speed and large errors in predicted power may occur.

A: We are aware of the fact that this treatment of the speed-power curve is not fully realistic. Assuming a ship is determined to sail at about 80% of the design speed when possible, external effects like currents and wind can enhance the real maximum cruising speed. Applying this artificially increased design speed to conditions without or contrary external effects would lead to underestimations of the vessel's engine load. Through a sensitivity run we estimated for vessels of class 6 (which have the largest share in fuel consumption) a worst case underestimation of ca. 9%. On the other hand, external effects can also lead to overestimations, so the underestimations for the entire year on the whole North Sea may be far below 9%. The most appropriate way to deal with external effects would be to take them directly into account provided these effects were known. This would require, however, a lot of data (for example about the ship's hull, drought, fouling, wind, currents, wave hight) that were not available. In our opinion, estimating all these variables would introduce many hardly quantifiable uncertainties.

n) Page 11286, L5-11: The part describing the BC emission factor is a refreshing



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analysis of the work done by Lack & Corbett. However, the rest of the two papers do not discuss BC at all. I would suggest dedicating a separate section for emission factors, because the only reference to emission factors is Zeretzke (2013) which is not available. Also, the load dependency of BC is one thing, but in their paper Lack & Corbett also propose a connection between fuel sulphur content and BC emission factors. I do not see that part in BC emission factor assignment at all. How is this feature taken into account?

A: The method to calculate the BC emission factor is described in more detail in section 2.4 now. Sulfur particle emissions are treated separately, which is also described in section 2.4.

o) Page 11287, L20-22: I do not understand the sentence starting "It quantifies also the differences...". Please clarify.

A: This sentence was changed into: "It quantifies also the differences normalized by the number of ships per size class - representing differences between average ships of the size classes - and the differences normalized by the transport volume per size class."

p) Page 11288, L7-12: There is no description of fuel consumption modeling, or how it is done, even if authors report fuel consumption results in Table 2. What values are used for specific consumption?

A: The fuel consumption modeling is now described in the modeling section.

q) Page 11288, L19-26: One difference which is directly visible is the neglect of ship emissions in port areas. It is not included in EMEP inventories, either, but the authors conduct CTM runs and compare to AQ observations, which include all emission sources, and then draw conclusions on the improvement made by using the newly developed emission inventories. I disagree with the statement made in L24-26 regarding the differences because a relevant part of the work (emissions from ships in port) was not done.

A: The statement about 35% possible overestimation is a citation, only supporting but not verifying the authors' opinion. We comment on the usability of the inventory for CTM calculations in the general comments.

r) Page 11292, L1-2: I disagree with the statement that SO4 is only from secondary aerosol formation. The work of Petzold et al indicate that 1-5% of fuel sulphur is actually converted to primary SO4. The discussion whether this contribution changes as a function of engine load is still open, though.

A: This is true. We reformulated this sentence to be more precise about the origin of sulfates in the atmosphere.

s) Pages 11292-11293: I agree that the significance of ship emission contribution to overall air quality is demonstrated with this discussion. However, it goes slightly off the mark with the improvement of correlation if ship emissions are present or not. In my mind, the real question should be "Is there an improvement when compared with the current ship emissions inventories?" The authors should run a comparison using EMEP emissions and the emissions generated by their ship emission model + do the consecutive CTM part in both cases. The difference in correlation coefficients between these two cases will indicate whether the quality of the inventories has improved.

A: Our primary goal was not to improve emission inventories, but to demonstrate the influence of ship emissions assuming our calculated emissions. What the reviewer suggests – to compare emission inventories – would have been beyond the scope of our study. (It may be worth an extra paper).

t) Page 11297, L17: I am guessing here that CCLM is the name of the ship emission model? Or is it Cosmo-CLM referred to in the consecutive paper? This abbreviation is undefined, please clarify.

A: CCLM is COSMO-CLM. We changed this in the text.



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u) Equations should be numbered

A: They are numbered now

v) Page 11302, Table 1: No difference is made between bulk cargo and container ships? Are you saying that big bulk carriers actually have 13 MW of auxiliary power installed and 0.3 * 13 MW is used during cruising as stated in P11285? I doubt this, even if vessels themselves have deck cargo gear for loading/unloading. The label "cargo ship" is a very wide one and significant differences exist between cargo ships built for different purposes.

A: The ship types we distinguish are tankers, bulk ships, cargo ships, cruise ships, ferries, tugs and other vessels. Table 1 is an example of the median values only for cargo ships, which include container ships. We shifted this table to the appendix together with tables for the other ship types.

w) Page 11316, Figure 7. These are hourly averages, right? If so, then the figure label should say so. Please, clarify.

A: Fig. 7 shows daily values.

x) Page 11317, Figure 8: Labels on the bottom image row is incorrect. Currently there are three "winter" and only one "summer".

A: This was corrected

y) Page 11319, Figure 10. The sulphate concentration in winter case looks odd. It looks like a boundary effect, since there is a very sharp contrast near the East edge of the box. True, Poland uses a lot of coal during winter, but this looks suspicious.

A: We may have used wrong data for this plot because we cannot reproduce it. We made a new plot with correct data.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 11277, 2015.



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