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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide" *by* J.-P. Jalkanen et al.

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Author response to anonymous referee comments on "Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide" by Jalkanen et al., ACPD, 11, 22129-22172, 2011.

Referee 1

General comments: Comments 1 & 2: This paper describes an "upgrade" (STEAM2) of a previously published model STEAM by the same authors. Although it is apparent that for example the treatment of auxiliary engines is substantially better in STEAM2, the paper seems to loose itself in many detailed calculations but more complex is also

less transparent and not by definition better. The main criticism of this reviewer is that section 3.4 and 4 do not tackle this issue. Clearly the authors have good data for the Baltic sea. I would like to see a simple comparison table of Baltic sea emissions of NOX, SO2, PM, EC (if available) for EMEP total (can be effortlessly downloaded from www.CEIP.at); STEAM and the new STEAM2. Are there significant variations and do these go beyond the uncertainty bounds resulting from the lack of exact fuel S contents? And if so why? are such changes explainable by the improvements of the STEAM2 model? There is no argument that AIS data allow better allocation of the ship routes but that is in a way independent of the STEAM2 model. In my mind these are the final and real interesting comparisons the paper should come to in the end to make it interesting for ACPD. Otherwise it is not about Atmospheric chemistry and physics but about model development for shipping alone – than I would recommend a more technical modeling journal. If the authors like they could split the Baltic in sections to highlight the geographical resolution compared to the previous model but for comparison reasons it is necessary to give also the value of the total Baltic Sea.

Author response: Chapter 3.4 has been revised to include a comparison between STEAM2 and EMEP inventories for the Baltic Sea. Discussion regarding the uncertainty of sulphur content in fuel was added and discussion concerning the accuracy of the assumption of total compliance with fuel sulphur content required by the SOx Emission Control Area was added. A new reference has been included discussing this topic (Berg et al., 2011). Discussion regarding the impact of fuel sulphur content changes on regional emissions was added to Chapter 3.4. Table 2 containing the STEAM, STEAM2 and EMEP emissions for years 2006-2009 was added and the differences between emission inventories is now discussed in Chapter 3.4. Figure 12 was revised to include also a spatial comparison with the corresponding EMEP emission values.

Detailed analysis of the Baltic Sea results for this period were left out this manuscript due to large volume of data, which would have made this paper too large to handle. A limited analysis was added to this manuscript and separate analysis of model results will be a topic for a consecutive publication.

Various detailed comments, 1: Abstract L3 & p22132 L2; “a few meters” – I assume this should be a few tens of meters.. just the uncertainty of exactly where the transponder is on such a large ship will cause such an inaccuracy. Not that this matters for the usefulness of the method.

Author response: This was corrected as suggested by the reviewer. The corresponding correction was also made to the introduction (to the paragraph addressing the properties of AIS transmissions).

Various detailed comments, 2, Introduction: Introduction fist 2 sentences (“ top to down” etc.) is a confusing paragraph. Basically any calculation using activity data will be a bottom-up method but the scale on which it is accurate may differ widely. It may not tell you anything about the location of the emissions. These emissions are than e.g. down-scaled through a distribution over a ship route map but we have little idea if this distribution is realistic or biased. In general the introduction should be reorganized, the points presented are valid but the order in which they appear is jumping from one to another and back again. It starts with methods, than jumps to scarcity of PM data, not mentioning other pollutants which appear only a page later.

Author response: This section has been substantially restructured to be more rigorous and consistent.

(i) It starts by presenting the context and background, i.e., a general description of the significance of PM from shipping, and possibilities for the reduction of these emissions (first paragraph).

(ii) Second, it presents a review of previous relevant research, and starts that by illustrating the current status of some of the known ship emission inventories (excluding the present study), and their benefits and drawbacks (second paragraph). Next, the issues of port emission modeling and the difficulties arising from lack of information regarding

the fuel sulphur content are discussed.

(iii) Third, the potential of the present modeling is briefly introduced. The use of AIS data in emission modeling is briefly described. Next, the basic differences of STEAM and STEAM2 are briefly presented.

(iv) Fourth, the main aims of the article are presented (the last paragraph in introduction).

Various detailed comments, 3 & 6: Introduction: OK but is this multi-engine set-up known for each ship?

Author response: Yes, this is one of the standard data fields provided by IHS Fairplay. If no data for a specific vessel is available, a single diesel engine is assumed.

Various detailed comments, 4: Introduction: the citation in this sentence is a bit strange, probably the sentence needs to be adjusted. Hulskotte 2010 and Cooper 2003 exactly determine the port emissions. So, the sentence could be something like: Although in port emissions have been determined before (H 2010; C 2003), these have been neglected in many previous etc.

Author response: These have been corrected.

Various detailed comments, 5 & 8: Yes this is correct. But is it (one of) the main uncertainty? If we not even have accurate PM emissions should the distinction between BC and EC be the major cause of concern? Do you expect variations in engine load where in absolute terms BC will increase and EC will decrease? Both are strongly correlated – so given all the uncertainties I wonder if this is a crucial distinction at present or should be a “next step”.

Author response, BC/OC issue: The discussion regarding the range of experimentally determined PM emission factors was added to Chapter 3.3 of the manuscript.

Designation of Black Carbon and Organic Carbon in Corbett et al. (2010) raises an interesting issue. If black carbon is defined as light absorbing component of carbon compounds how is organic carbon defined? The division in Corbett paper is probably done because climate change studies are accustomed of using BC as a form of particulate matter which has an impact on climate. This is acceptable, but if organic carbon is reported as well (like in Corbett et al 2010), is the component of BC which contains organic components then subtracted from the total organic carbon emissions? If not, then some double counting will occur, significance of which can be up to 30 %. The division of PM to subcomponents is relevant because for example the climate impact of certain components is larger than others. Measures to reduce PM emissions of ships have mainly concentrated on reducing the amount of sulphur in the fuel. This however, affects the emissions of some PM components, but not all. To assess the effectiveness of SOx Emission Control Area rules this dependency should be included in the ship emission inventories. Ongoing projects and epidemiological studies will provide some insight on the health response of PM components.

According to Agrawal et al. (2008a,b;2011) and Petzold (2010) the OC component of PM is strongly dependent on engine load. We are not aware of sufficiently detailed studies, which would show the black carbon/organic carbon ratio as a function of engine load. Engine manufacturers probably have this information, but often this data is not public. It is difficult to say how significant this difference is, but OC emissions increase greatly at low engine loads. One of the reasons for the changes in EC/OC ratio could be the consumption of lubricant oil when sulphur in fuel is reduced as the reviewer suggested, but this effect is not currently included in STEAM2. Further experimental work is needed to produce information of the role of the lubricant oil in exhaust emissions of specific PM components.

Various detailed comments, p22134 L17: So, does HIS provide the previously mentioned multi-engine setups?

Author response: Yes, this is one of the standard data fields provided by IHS Fairplay. If no data for a specific vessel is available, a single diesel engine is assumed.

Various detailed comments, 7: p22136 L 12: Indeed using the avg speed is not very accurate but can you indicate on which geographical scale level such deviations are significant? On the other hand it can be argued that the inertia of large ships is causing a certain time lag in actual speed versus power. In ship trial procedures minimal run lengths are between 2 and 3 nautical miles. Such distances are required in order to get accurate results for power-speed relations at constant speed. When speeds are changing larger distances will have to be considered since there is a time lag between power and speed depending on acceleration or deceleration. So on which scale levels the output of the STEAM and STEAM2 can be considered as accurate between certain boundaries?

Author response: Neglecting the true speed of a vessel or speed variation during voyage will have the largest impact on CO emissions, but also SOx and PM will be affected. Use of average speeds may give a wrong geographical distribution of emissions, because no speed changes are allowed during voyages. Congestion inside port areas can lead to long waiting periods outside ports when ships are waiting for access to the pier despite the use of normal cruise speed during voyage. In these cases the use of arrival/departure times will lead to average speed which is too low.

Furthermore, comparison of stack measurements against the STEAM2 predictions is possible, because the model produces estimates of instantaneous emissions. This offers an opportunity not only to assess the accuracy of emission estimates of single vessels, but gradually can be used to validate the regional ship emission inventories as well. Emission estimates from international shipping have received a lot of criticism from ship owners, because they oversimplify and generalize important effects, like voluntary use of emission abatement techniques, speed changes, fuel sulphur content and environmental conditions (waves, ice, currents). Waves, vessel specific fuel sulphur content and abatement techniques are already taken into account in STEAM2 and the work to include the effects of sea ice and currents is in progress.

Acceleration and deceleration effects have been investigated and a crude method to include CO emissions during rapid engine load changes has been included, but this topic requires further study. It is possible to determine acceleration and deceleration from changes of vessel speed, but the existence of external effects, like sea currents, complicates this issue. Extensive datasets of engine operational data from a large number of vessels would be required to construct a more reliable way of estimating the effects of inertia in more detail.

Last comment: p22144 & Fig. 3. Especially the relationship between EC and OC emission is not so easy to follow and check. The scale in fig 3. is good for looking at the SO4 but the line suggests that OC is decreasing with S content of the fuel while EC is increasing? Is that correct? if so any idea why?– maybe Fig3 should have a 2nd Y axis to show the OC and EC properly? From literature (Lack et al.,2009) it is suggested that S-content and EF-OC are strongly correlated which can easily be understood because cylinder feed lubricant oil is dosed in order to neutralize fuel-related acidity. Lubricant oil may be the most important source of OC. The relationships derived in STEAM2 seems to neglect such relationship?

Moreover, it is clear that you have to make a choice but in the literature quite some variation can be found in OC contents EC to S content – so somewhere the range has to be discussed. These 3 digits behind the decimal point suggest a very high accuracy and it is doubted if that is entirely correct. Furthermore the exact S% is often not known: : :it is know that it is less than x % (the max allowable limit value) but exactly how much can vary from ship to ship and this is unknown. This should come back in the discussion on p 22148 section 3.3. – it is good and correct that you compare with studies with exact known S% but it should be made explicit that in the next step (real world) you will not know this and replace it again by average values: : : what ranges does that create? relevant; irrelevant?

Author response: The figure illustrating the PM component emission factors as a function of fuel sulphur content has been revised by using a second Y-axis for EC, OC and Ash. The data in this figure are those of Buhaug et al. (2009). STEAM2 does not

include any contribution from lubricant oil. However, this could be added in the future if sufficiently detailed experimental data becomes available. In STEAM2, emissions of OC do not depend on fuel sulphur content, which is now stated in Chapter 2.3.2 and illustrated in new Fig 3,. Some variability of EC and ash emissions as a function of fuel sulphur content exists, but this dependency is difficult to quantify because of the large scatter of literature data. Different fuel grades may also contain variable amount of ash, which is not currently taken into account by STEAM2. A new image (Figure 5) has been added to clarify the treatment of OC emission factor in STEAM2, which is described by Eqs 13-14.

The constants describing the SO4 and water dependency on fuel sulphur content (Eq 13a-13d) were obtained by linear regression of the data illustrated in Buhaug et al (2009). This is indicated in the text just above Eq 13a. In our opinion, presenting the constants of linear regression analysis with insufficient number of decimals can lead to unexpected behavior of the proposed model.

Discussion of the uncertainties in marine fuel sulphur content was added to Chapter 3.4 and an alternative fuel sulphur content values were tested with the model. The impact of lowering the 1.5%/0.5% fuel sulphur content to 1.0%/0.1% in the Baltic Sea area decreased the SOx emission by about 20 %. This effect was tested using one year of AIS data. A new reference was added (Berg, N., Mellqvist, J., Jalkanen, J.-P. and Balzani J., Ship emissions of SO2 and NO2: DOAS measurements from airborne platforms. Atmos. Measur. Tech. Discuss., 4, 6273-6313, 2011.) illustrating the performance of STEAM in situation where the fuel sulphur content is unknown. However, this uncertainty is not large enough to entirely explain the difference in SOx, PM and especially CO emissions between STEAM2 and EMEP alone, because it is most likely that methodological differences in emission inventory construction can have a larger effect. This concerns auxiliary engine usage profiles in particular because this information is less complete in EMEP data than in STEAM2 database of ships.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/11/C14635/2012/acpd-11-C14635-2012-supplement.pdf

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