Author response to critique concerning the manuscript "A comprehensive inventory of ship traffic exhaust emissions in the European sea areas in 2011" by Jalkanen et al.

General remarks from the authors

We thank the referees for their comments. The results of this paper have been rerun with the most recent STEAM version. This has lead to some numerical changes; tables and figures now reflect these changes. Further, some additions were included, which were not addressed in the referee comments. In our opinion these additions will make the content of this paper more relevant to a wider audience. For example, in Table 1 there is an entry for inland shipping as well as emissions as a function of vessel size categories. Table 3 now includes average cruising speed of vessels found in AIS as well as their overall contribution to total CO2 emissions.

These additions can have important implications, because official statistics of ship emissions usually distinguish between inland and other shipping. Also, the size categories help to assess the significance of the exclusion of vessels under 5000 tons from EU MRV initiative (vessel specific reporting of CO2 emissions; the Monitoring, Reporting and Verification regulation 2015/757/EC). Inclusion of actual vessel cruising speeds is now consistent with the results reported in the 3rd IMO GHG study. This helps the reader to assess the extent slow steaming is practiced with ships sailing the study area.

Detailed responses to referee comments

Response to Referee 3

Referee3:

What I am missing, however, is a clear explanation and motivation, how these things connect to atmospheric science. (Remember, you submitted to ACP!) In its presentversion, the article could well appear in a journal for transport science, with no connection to the atmosphere at all. I therefore suggest to expand particularly the introductory part of the manuscript, providing more motivation why this work is so important, and how it connects to research activities in the atmospheric domain (modelling, climate studies, health studies?).

Authors' response

While it is true that that it is possible to publish the manuscript in one of the transport journals, we would like to stress the significance of this work to the air quality community. This work will help to decrease the uncertainty regarding the evaluation of emissions from the transport sectors, which is a major challenge to air quality modeling. The publication of this work in ACP will have at least the following implications:

a) Clear improvement of ship emission inventory concerning the temporal and spatial description as well as the variation of emissions. Emission inventories are no longer static maps with constant geographical distribution, but fully dynamic reflecting the underlying true ship activity.

b) Possibility for evaluation of uncertainty of emissions by conducting vessel specific emission modeling and measurements. Stack measurements can be directly compared with the modeling work reported in this paper.

c) Large scale validation of regional ship emissions using satellite data. The comparison between the work of Vinken et al and this work are already discussed in the paper. Both of these approaches are independent of each other and they both indicate that existing ship emission inventories for the Mediterranean Sea are too large with regard to NOx emissions. This warrants further work which is urgently needed at the policy side, because the environmental legislation of the maritime sector is in turmoil.

e) The starting point of many air quality studies are the emissions provided by EMEP. If the accuracy of ship emission inventories of EMEP can be improved with the current work, it may help to reduce the uncertainty of air quality modeling studies and consecutive impact assessments.

With these points in mind, we have modified the Introduction -section and added the following text to the beginning:

"The cornerstone of air quality modelling research is an up-to-date description of emissions from all sectors of anthropogenic (i.e. industry, agriculture, transport) and non-anthropogenic (i.e biogenic, desert dust, wildland fires) activities. However, information on emissions may have limited dynamical features, such as the geographical or temporal variations of emissions. This is especially important for transport emissions, which vary substantially both spatially and temporally."

We also restructured the Introduction –section to respond other comments of the referees.

Reviewer3:

"Why are ship emissions so important for atmospheric effects, for atmospheric modelling and/or science in general? (You may add references to some key atmospheric model works here.)"

Authors' response:

It is often the case that major cities also have large harbors. Good examples of these cases are the English Channel, St Petersburg, Istanbul, Hong Kong and Singapore. In these cities, ships are very close to significant human populations and it may result to significant health implications. It is also very difficult to match the air quality modeling work with corresponding measurements if the input data, i.e emissions are not accurately described. We have reported the results using CO2 emissions as a baseline because of GHG emissions from ships are currently discussed at IMO and EU level and there exists a requirement in

EU for ships to report their fuel consumption on annual bases starting from 2018 (the MRV initiative, Monitoring, Reporting and Verification of GHG emissions). In order to help formulate a sensible policy for ship emission limits, one must have an idea of the potential costs and benefits of each change. For example, sulphur reductions in marine fuels can be justified with reduced human health effects, because benefits outweigh the costs. It is imperative that all relevant legislation concerning ship emissions are included in a proper way, which is the case in our work.

Further, we offer a possibility for any researcher working with ship emissions, a possibility to use their own fuel based emission factors which is possible through fuel consumption (CO2 emissions) modeling. Using CO2 as a baseline allows readers to assess the fuel consumed in each grid cell and facilitates the use of different emission inventories if the readers are not confident that the ones used by the authors are sufficiently accurate.

These issues are discussed in section 3.1 and we have added several references to relevant ship emissions/air quality vs health studies:

Jonson et al, ACP 2015

Bosch et al, 2009, cost benefit analysis to support the impact assessment accompanying the revision of directive 1999/32/EC on the sulphur content of certain liquid fuels, AEA Technology, European Commission report ENV.C.5/FRA/2006/0071

Corbett et al, 2007

Brandt et al, 2013

USEPA, 2008, Regulatory impact analysis control of emissions of air pollution from locomotive engines and marine compression ignition engines less than 30 liters per cylinder

Reviewer3:

"I assume that your updated ship emissions are to be used in atmospheric modelling. Can you make a a priori guess (non-quantative) what the expected benefits/impacts will be if an atmospheric model uses your updated ship emissions in contrast to the existing inventories?"

Authors' response:

Yes, this has been tested using the SILAM model, but the results have not been published yet. Our preliminary analysis indicates that modeled concentrations are in better agreement with air quality measurements of coastal stations than with the existing ship emission inventories. So far, this analysis has mostly concentrated in the Baltic Sea region, but a logical extension to other sea areas can be made.

Just as an example of these comparisons, Figures 1 and 2 present a case study for the Baltic Sea area. Two ship NOx emission inventories, one from current work and the other from TNO/MACC are compared to AirBase measurements. As can be seen with the STEAM case (Fig 1), the colors have shifted from bluish tones towards green and yellow, which indicate a better fit to experimental air concentrations of NOx. Largest changes are visible in the Polish coast and the Gulf of Finland.

We have also compared the STEAM ship emissions and SILAM chemical transport modeling results with satellite observations of NOx, but this analysis is not complete, yet. We would like to stress the preliminary nature of these conclusions, but it seems that in the Mediterranean Sea STEAM ship emission inventories are in better agreement with satellite NOx observations than TNO/MACC. For ship emitted sulphur, however, satellite observations are very difficult and the SOx signal is too weak to be seen. In the future, we will extend the AirBase/SILAM comparison to Mediterranean stations to get more insight on the SOx emitted by ships and its contributions to overall air quality in South Europe.

Of course, the overall contribution of Baltic Sea shipping to NOx concentrations is about 10 % from of airborne nitrogen (annual average) and improvements larger than this can hardly be expected.

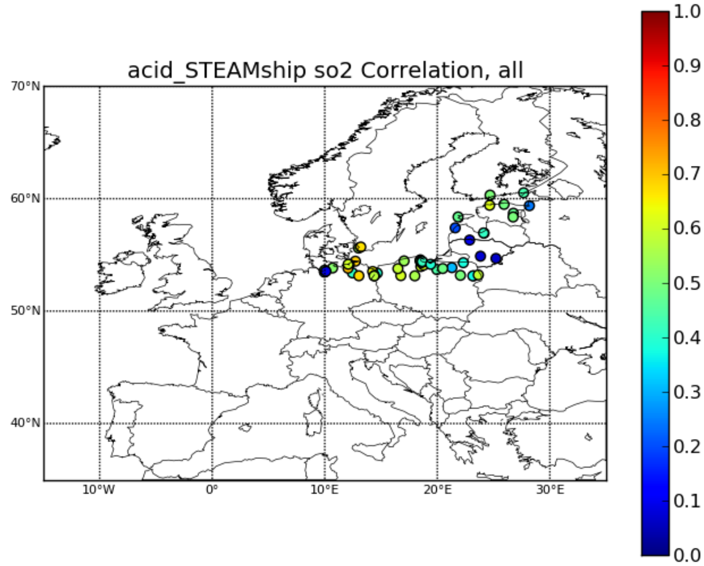

Figure 1. Comparison of SILAM modeling (with STEAM ship emission inventories; TNO/MACC for all other emission sectors) and air quality measurements. Correlation coefficients are indicated by the color scale.

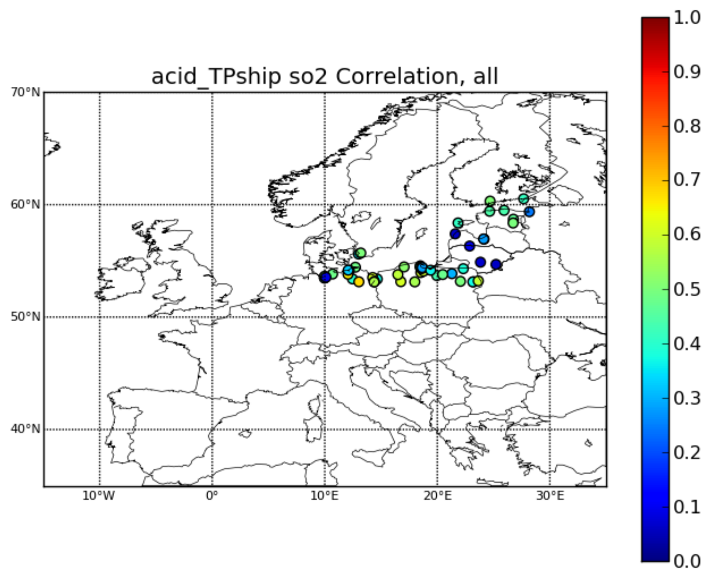

Figure 2. Comparison of SILAM modeling (with TNO/MACC emission inventories) and air quality measurements. Correlation coefficients are indicated by the color scale.

Referee3:

“I am somehow missing a statement on the consequences of the findings of this paper (STEAM simulations disagree with EMEP inventory.) Does this imply that atmospheric models should try to incorporate your inventory, or your ship emissions model? Who could be the user of the results/products/methods of your research? Can your inventories be made available to other atmospheric researchers (e.g., through a website or a data base)? This would greatly enhance the usefulness of your work.”

Authors’ response:

In our opinion, the ship emissions in the Mediterranean Sea warrant further study. There are already three independent reports (Vinken et al; Marmer et al; our study) which indicate that ship emissions in the Mediterranean Sea might be too high when compared with the EMEP inventories. Currently, annual EMEP reporting does not require ship emissions reporting from member states, because they are done separately by an outside contractor. We have shown that from technical point of view, it is possible to revise the ship emission inventories by incorporating real vessel traffic data and emissions modeling in such a manner that the work is based on sound technical principles instead of more general way. This can be done on annual basis, if AIS data and funding for the work are available.

The following was added to the Conclusions section:

“A logical step would be to include chemical transport modeling and comparisons with air quality measurements of coastal stations to determine whether modeled NOx and SOx concentrations are in line with measurements.”

Sharing the emission datasets generated in this work is warmly recommended. We have confirmed from the European Maritime Safety Agency that the gridded emission output of STEAM can be made available upon request. See the first page of this manuscript for contact details.

We have added the following to the end of the Discussion section:

“The emission outputs of STEAM can be made available for further research upon request to the authors.”

Referee3:

l. 8 "Emissions originated from ship traffic in European sea. . ." -> "Emissions originating from ship traffic in the European seas. . ."

Authors' response:

This was corrected

Referee3:

Update the references list.

Authors' response:

List of references has been updated

Response to Referee1

line14-15; p7471. In this discussion it should be noted that the most trafficked river in Europe is the Rhine which ends in Rotterdam; the biggest European port. AIS for non-recreational inland shipping has been subsidized in the Netherlands (and by now is compulsory). This explains a much higher share of small vessels in the Netherlands compared to other countries with much less important inland shipping routes.

Authors' response:

Thank you for pointing this out. This explains the large share of small vessels in the Dutch fleet. This is now explained in Section 3.2.

"The large number of small vessels in the AIS data in the case of the Dutch fleet can be explained by the fact that the use of the AIS equipment is compulsory in the non-recreational inland vessels in the Netherlands. In Finland, there are over 190 000 motor boats (Trafi, 2014) and 525 Finnish vessels were picked up by AIS in Europe. Clearly, the representation of small vessel traffic substantially varies between countries; their activities are incompletely represented in the AIS signals."

Referee1:

The contents of Table 3 should be discussed in a bit more detail, especially the very high % of auxiliary engines (AE) (= 100%- ME%) should be explained and /or commented on: There seem to be many ships where AE% is > 40% and sometimes higher than 50% - which makes one wonder what the main engine really is if it is only used for 30-50% of the time. It seems that in several cases the ME could be used for tasks that the AE performs when in port? So how do you know they use only the AE?

Authors' response:

We have given this a bit more thought.

First, we have rerun the model with the most recent model version, because some changes have occurred since the results of this paper we generated. This has changed the numbers somewhat and we have updated all the corresponding figures and tables. The changes involved concerned especially the aux engine timer which regulates the use of aux engines in cases where ship remains stationary but it still sends out frequent AIS position reports. These periods were previously modeled with hoteling AE usage assumptions regardless of the duration of hoteling period. In the most recent model version hoteling has been divided into two parts, "hoteling" and "berthing" modes, which means that "berthing" mode will have a reduced AE usage compared to "hoteling". The rationale of this is that when cargo operations are finished, the need for AE power is gradually reduced. This approach is similar to the work done for Port of Long Beach (Starcrest LLC, http://www.polb.com/civica/filebank/blobdload.asp?BlobID=10194, Table 2.12) emission inventories, but it still needs to be confirmed with future experimental work. This has a direct impact on the auxiliary power need of vessels. The details of this feature can be found in the Interactive Discussion of Johansson et al, 2013 ACP paper.

Second, we did a comparison of the 2nd GHG study results for the assumptions regarding the use AE power and the fuel consumed in Main and Aux engines (see Buhaug et al, 2009, Tables A1.25 and A1.8) and comparison to values of Table 3 of our work. In the 2nd IMO GHG study there exist vessel classes which consume more than half of their fuel in Aux engines, too. Further, we have introduced two more columns to Table 3 which indicate the average vessel cruising speed and the share from total CO2 produced. The addition of average cruising speed gives the reader an opportunity to assess the extent of slow steaming in EU area and the %CO2 produced indicates the significance of the ship class in relation to total CO2 produced. It can be seen that those vessels which use more than 50% of their fuel in Aux engines are Service vessels and tugboats. This is well in line with the 2nd IMO GHG study. Further, the contribution of these vessels to total CO2 output is relatively small, less than 2.5%.

Third, the auxiliary engine usage logic is done with the following method (see Figure 3 below). The model evaluates the need for power other than propulsion by looking at cargo and passenger capacity of the vessel as well as the operating mode. Based on these numbers, the power needed by ship systems is evaluated. Once the required kilowatts are predicted, then the model looks at the engine setup of the vessel. How is power transmitted to the propeller, is it a 2-stroke engine with direct connection to the propeller? Is there a reduction gear or power take-off in between? Is the propeller fixed pitch or controllable pitch type? These are used to determine whether it is possible for a ship to use its main engine in power generation with a shaft generator or are aux engines needed for power generation. In the model it is assumed that shaft generators are only used during the cruise mode, not during hoteling or maneuvering modes. If the power transmission is electric (diesel-electric vessel) then the additional power need required by ship systems has to come from main engines.

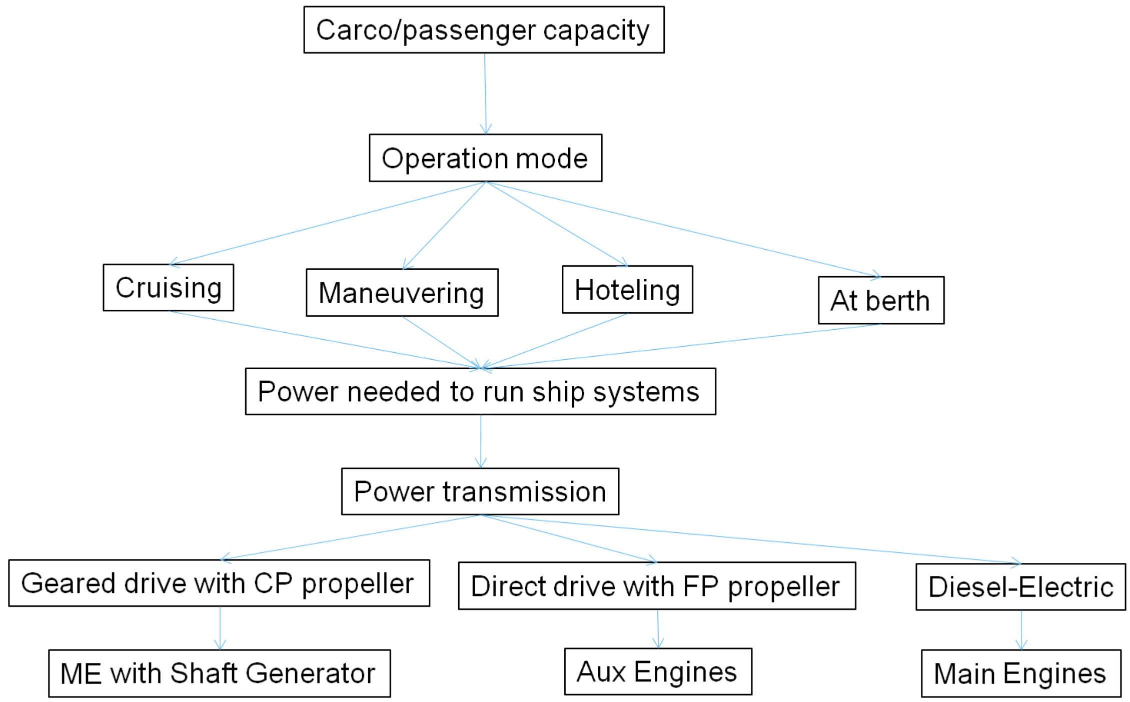

Figure 3. Aux Engine usage determination in STEAM. It should be noted that in the model the use of shaft generator is only assumed during the cruise mode.

We have modified the Section 3.3 to:

"The shares of fuel used by the main engines have also been presented in Table 3, these have also been evaluated by the model. The amounts of fuel used in main and auxiliary engines depend not only on vessel specifics, but also its operational profile. However, there is a major uncertainty in the predictions of the fuel consumption of the auxiliary engine, as the use of an auxiliary engine varies greatly, even for ships of the same type. The use of auxiliary power cannot be determined from tank tests of ship resistance, unlike the power needed for propulsion, for which various theories exist for performance prediction. In this study, we have used the methodology presented previously (Jalkanen et al, 2009; 2012, Johansson et al. 2013). This method combines the information on cargo capacity, auxiliary engine power profiles, main and auxiliary engine setup and power transmission method. However, there are also other modelling approaches, which are based on extensive vessel boarding programs (Starcrest, 2013), local knowledge and pre-assigned contributions (Dalsoren, 2009). The share of auxiliary engine fuel consumption from total consumption is very high for Service vessels and Tugboats. This is consistent with the 2nd IMO GHG report of Buhaug et al (2009), but the contribution of these vessels to total fuel consumption or CO_2 emission from shipping in the study area is quite small, less than 2.5%."

Referee1:

l5-10 p7473 - discussion on uncertainty here seems related to the above comment on Table 2.

Authors' response:

Could this comment relate to table 3 instead? Table lists CO2 hotspots and their contribution to overall CO2 emissions. If so, the points listed in the previous bullet point of the author response are valid in this context, too.

Referee1:

p 7474 - bottom of page: There appears a bit of inconsistency in the reasoning here - while the argument now is that the current 2011 estimate is in line with Vinken et al. for 2006 - a bit earlier in the paper it was argued that it made sense that NOx emissions were lower due to the economic crisis of 2008-2009. Vinken et al. is before, this paper is after. Please give some interpretation / comment on this.

Authors' response:

Despite the difference in study periods, Vinken et al: 2006, this work: 2011, some general conclusions can be made. Vinken et al report NOx emission for the EU area as 1.0 TgN whereas our study suggests 0.9 TgN. Vinken et al state that for the Mediterranean Sea, EMEP values are too high, which was also found in our study. We have removed the Baltic Sea discussion concerning the comparison of Vinken et al and our work from this manuscript. First of all, the analysis of Vinken et al concern snapshots of a densely trafficked shipping lane in the Baltic Sea, not the Baltic Sea in its entirety. For this ship lane snapshot area, Vinken et al report that EMEP emissions are underestimated. Further, Vinken et al give 40-60% uncertainty in their satellite based top-down emission inventory. It may be worthwhile to do a more thorough comparison using STEAM and the approach of Vinken et al in the future, but it was not done in this study. It should also be noted that EMEP has recently updated their emissions for all sea areas for 2011. The new inventories are closer to our work than before.

In addition to the removal of Baltic Sea ship emission comparison, we have added the following in Section 3.4:

"The difference between the NOx emissions of the STEAM and EMEP inventories in the Baltic Sea shipping is 18% (the emission values of STEAM is higher). However, the comparison with Vinken et al. (2006) is challenging for the Baltic Sea, as Vinken et al. (2006) report only emissions along the major ship tracks, which are not representative of the emissions in the whole of the Baltic Sea area."

Referee1:

In section 3.4 the EDGAR inventory is missing - would be good to include this next to EMEP as it is one of the most widely used inventories.

Authors' response:

This is a good suggestion, but unfortunately in EDGAR inventories we could not find area definitions which would summarize emissions by sea area (http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2013). Instead, a total number is given for CO2 emissions from global international shipping during 2011, which is 606 million tons. This number is lower than the value reported in the 3rd IMO GHG study, which lists the global international shipping contribution as 850 million tons. The methodology used in the 3rd IMO GHG study is very close to the one used in our work and it is likely that values provided by EDGAR database for EU area may be lower than the ones we report. The EDGAR inventories are based on top-down fuel sales statistics of IEA, which have been compared to the bottom-up modeling in the 3rd IMO GHG study.

It should be noted that we have not conducted any detailed area by area analysis between EDGAR and STEAM, but it should definitely be part of the future work.

Referee1:

l8 and further p7475: The SO2 emissions are directly related to the S content of the fuel - so the conclusion can only be that the EMEP inventory has about 2 x the S content.- which seems unlikely - At the same time it seems unlikely that this factor 2 can be entirely covered by the in-port emissions which may use lower S fuels (or if so please calculate and explain) - so a bit more discussion is needed here - for example what is the role of the high % of AE in this study (see Table 3) - can that help to partly explain the gap?

Authors' response:

We have no knowledge how EMEP sulphur content assignment for marine fuels is done, but in STEAM fuel type assignment is done based on engine characteristics. The model evaluates whether engine stroke type, crankshaft revolutions per minute and engine power output are suitable for the use of residual fuels. This assignment is done based on the book "Diesel Engines for ship propulsion and power plants" by K. Kuiken (Target Global Energy Training, Onnen, the Nethrlands, 2008). When suitability for residual/distillate fuel is determined, STEAM assigns fuel sulphur content for each engine taking relevant legislation into account. For example, for passenger vessel in SECAs this would lead to 1.0%S during year 2011. Similar analysis is conducted for aux engines. Also in these cases, the suitability for residual fuel use will depend on aux engine characteristics and whether the ship is in EU harbor areas or not. Of course, we cannot fully predict correct fuel sulphur content for vessels which would be capable of using residual fuels, but the ship owner has voluntarily decided to use distillate fuels with lower sulphur content than what is required by the law. We have the opportunity to assign sulphur content vessel by vessel for ME and AE separately if bunker delivery notes from vessels have been made available for us. Unfortunately real sulphur content is known only for handful for vessels (less than 50 cases), but real values could be used in STEAM.

It should be noted that EMEP has revised their emission inventories in 2015 and the SOx emissions in the Mediterranean Sea have been reduced significantly, from over 1300 to 957 thousand tons. Regardless, the values reported in our work (595 thousand tons) is still about two thirds of the EMEP values, but the EMEP 2015 update for 2011 results brought their values closer to our work.

Plotting the EMEP timeseries of SOx and NOx from Mediterranean shipping indicate that NOx and SOx emissions decreased in a similar way during 2007-2010, probably reflecting the overall decrease in shipping and economic activity (Fig 4).

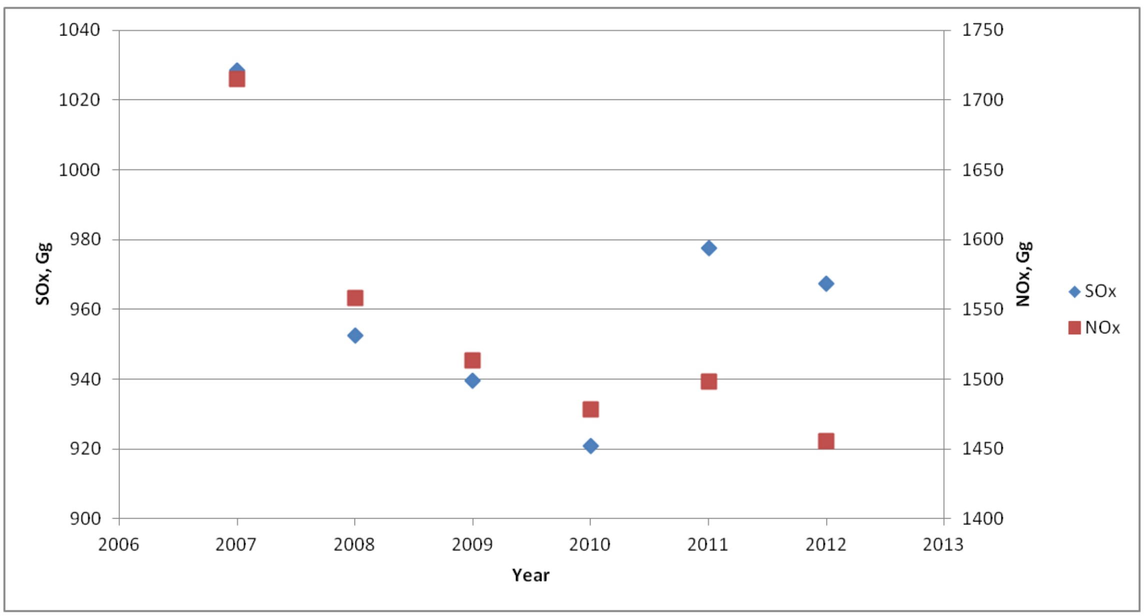

Figure 4. EMEP timeseries of NOx and SOx emissions from Mediterranean Sea shipping. All values are in Gg, taken from http://www.ceip.at/ms/ceip_home1/ceip_home/webdab_emepdatabase/emissions_emepmodels/

As can be seen from Fig 4, from 2010 onwards SOx emissions in EMEP Mediterranean ship emission inventories increased by over 6% whereas NOx emissions from ships increased only by 1.4%. Assuming that NOx values reflect the change in shipping activity (not taking the IMO Tier II rules for NOx into account), it is curious that SOx emissions have increased more than NOx, because at the same time EU sulphur directive came into force in January 2010. This required reduction of marine fuel sulphur content in harbor areas and has additional requirements for passenger vessels outside the ECAs. These changes would have been expected to decrease the SOx emissions from Mediterranean shipping from 2010 and onwards, not to increase them. This warrants further study and should be confirmed with air quality measurements.

The SOx emission values reported in our work for the Mediterranean Sea are 594 800 tons (in SO2). At the same time, the CO2 emitted is 48 344 100 tons. These values correspond to 297.7 Gg of S and 15.5 Tg of fuel (assuming weighted CO2 to fuel conversion factor 3.113 g/g of CO2). This leads to average fuel sulphur content of 1.9% for the Mediterranean shipping. It should be noted that the fuel used in harbor areas must comply with the 0.1%S requirement (and passenger vessels with 1.5%S), which lowers the average sulphur content of ship fuels in the Mediterranean Sea. In our work, residual fuels have been assigned fuel sulphur content of 2.7%S. Calculating backwards from values in Table 3, the average fuel sulphur content of some major ship types are 1.91%S for containerships, 1.64%S for tankers, 1.2%S for RoPax vessels and 1.4%S for cruise ships. It should be noted that these values have contributions from both fuel used in Main and Aux engines and a large part of these fleets sail the SECAs.

We have added the following to Section 3.4:

''*Plotting the EMEP timeseries of SO_x and NO_x for the shipping in the Mediterranean indicate that the NO_x and SO_x emissions decreased in a similar way during 2007-2010, probably reflecting the overall decreases in both shipping and economic activity. However, between 2009 and 2010, the SO_x emissions in EMEP inventories increased by more than 6%, whereas the corresponding NO_x emissions from ships increased only by 1.4%. At the same time, the EU sulphur directive came into force in January 2010, with requirements for the reduction of marine fuel sulphur content. This would have been expected to decrease the SO_x emissions from the shipping in the Mediterranean, instead of increasing them. However, in 2010 the new NO_x limits (IMO Tier II) were implemented for vessels constructed since 2010 , but in 2011 only 3% of the fleet were new ships. Calculating backwards from SO_2 values of Table 1, the average fuel sulphur content (denoted here by S) of some major ship types yields 1.9% S for container ships, 1.6% S for tankers, 1.2% S for RoPax and 1.4% S for cruise vessels. It should be noted that these values represent a combination of SO_x from both main and auxiliary engines, which may use fuels with different fuel sulphur content. Also, these averages include contributions from vessels sailing both the SECA and the non-SECA's. The differences in the STEAM and EMEP inventories warrant further study; these differences should also be examined using dispersion modelling and air quality measurements.* ''

Referee1:

l 10-11 7476 - please recalculate both to CO2 or both to tons of fuel - not 1 as fuel and 1 as CO2 - this is for the reader very inconvenient.

Authors' response:

This has been corrected

Referee1:

l 18 p 7477 - The authors mention correctly the importance of the high resolution for AQ and health studies. However, to support this point the reviewer would also like to know about accessibility of the data for other scientists. Are they available upon request? or in other ways?. it is fine to say that this data will improve air quality and health studies but that is only true if the data are available for use.

Authors' response:

Yes, the emission grids can be made available for further study. We have added the following at the end of the manuscript:

"The gridded emission datasets of this work can be made available for further research upon request to the authors."

Referee1:

l12 and further p7478. This paragraph is not conclusion but belongs in the introduction or possibly somewhere in the discussion section. Last but not least in the Conclusions something more should be said about the large discrepancy in SOx emissions for the MEd Sea between this work and EMEP / IIASA . Now it is only mentioned. But as said earlier SOx emissions are simply and directly controlled by the S content of the fuel. So the fuels assumed to be burned in these studies are very different - how likely is that and how can it be explained or - if it can't be explained what kind of data or research is needed to solve this?

Authors' response:

We have moved the paragraph to the Introduction section.

We have also modified the beginning of the Conclusions –section to:

"The comparison of emitted pollutants with existing ship emission inventories revealed that there are some differences between the estimates of the various inventories for the emissions of ships sailing the Mediterranean Sea, whereas the results were better in agreement for the North Sea and the Baltic Sea regions. The NO_x, SO_x and CO emissions evaluated in this study for the Mediterranean Sea were 18%, 39% and 49% lower than the corresponding values in the EMEP and IIASA inventories. The $PM_{2.5}$ emissions from the STEAM inventory were 24% lower than indicated by the EMEP emission inventory. Satellite observations using the Ozone Monitoring Instrument (OMI) also indicated smaller annual emissions of NOx in the Mediterranean,

compared with the predictions of the EMEP inventory. These differences should be investigated further with a longer ship emission time series, which takes into account the relevant changes of the environmental legislation . From a technical point of view, it is feasible to have annual updates of bottom-up ship emission inventories.

Further research is required including emission modelling in combination with consecutive chemical transport modelling, comparisons with measured atmospheric concentrations of pollutants and source apportionment. The reasons for these deviations between different emission inventories should be investigated further and confirmed with independent experimental datasets, as these can have significant policy implications concerning health and environmental impact assessments within the transport sector. A logical step would be to include chemical transport modeling and comparisons with air quality measurements especially at coastal stations to determine, whether the predicted NO_x and SO_x concentrations are in an agreement with the measurements."

Referee1:

further minor comments. line 16 p 7461 "Furthermore, important emission sources, like harbours have been often neglected from regional emission studies." This statement needs to be either better specified or removed. Harbours contain many different sources; International shipping, inland shipping, refineries, handling of goods, mobile machinery for unloading etc etc. . There will be no national or regional inventory with zero emissions in ports. (they might be incomplete though)

Authors' response:

This has been modified to:

"Furthermore, important emission sources, like ships in harbours have been often neglected from regional emission studies."

Referee1:

line 6, p7466 - The sulphur content of the fuel has been modelled explicitly for each vessel... This needs some clarification. There are regulations by Sea (e.g. SECA) and the avg fuel S content in shipping is known but I don't see how you can model the fuel S content by ship. There will be ships with lower than avg fuel S and some with higher S content than avg but how to know which is true for an individual ship w/o actual sampling and measurement?

Authors' response:

This is described in the earlier responses to reviewer1. Please see the comment regarding the Aux engine usage modeling and the discussion regarding large differences between EMEP SOx and STEAM SOx inventories. In short, the fuel type assignment (residuals or distillates) is done based on engine stroke type, power and crankshaft revolutions. If the engine is capable of using HFO, HFO is assumed. Sulphur content is assigned per vessel and for ME and AE separately. This depends on relevant legislation (IMO Marpol Annex VI, EU directives), geographical area and the time period under study. We assume all vessels to comply with these requirements. Of course, voluntary use of low sulphur fuel in cases where dirtier fuel would be possible cannot be described accurately without knowledge of actual fuel sulphur content. Same applies to use of illegal high sulphur fuel. These features cannot be modeled correctly without sampling the fuel carried onboard the vessels.

Referee1:

l2 7473 habe = have - In general it would be good to ask someone to check for missing cases of the word "the" or "a" - this happens occasionally in the text but it takes me too much time to identify page and line numbers to list them.

Authors' response:

The typo pointed out has been corrected. We have done our best to check the language for missing articles.

Referee1:

The legend of Table 1 refers to Annex II for details but no Annex is present or given.

Authors' response:

Reference to Annex was removed from Table 1 legend.