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Discussions

Interactive comment on "Effects of strengthening the Baltic Sea ECA regulations" *by* Jan Eiof Jonson et al.

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We, the authors, thank the reviewers for constructive comments and suggestions

Below we list the comments from reviewer 1 followed by our reply reference to any changes made in the paper.

General comments

1) However, the paper falls short in precisely addressing the effects of the ECA regulations. The paper refers in many places to the use of the presented model results in upcoming studies that are in preparation. To improve the presentation, I recommend to better emphasize the objectives of this study and the value of the model calculations in itself by deriving recommendations for emission control policies.

Answer: We have added new material to the conclusions reflecting these comments.

Presently there are no further emission mitigation regulations targeted for the Baltic Sea and the North Sea apart from the NECA regulation entering into force in 2021. This regulation is expected to result in gradual reductions in PM2.5 concentrations and in depositions of nitrogen from BAS shipping, as shown in our calculations for future versus present conditions. The relative reductions are largely comparable to the decrease from other anthropogenic sources in the region. However, according to IMO (2018) the target set by IMO is "to reduce CO2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and GHG emissions from international shipping to peak and decline as soon as possible and to reduce the total annual GHG emissions by at least 50 % by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the vision as a point on a pathway of CO2 emissions reduction consistent with the Paris Agreement temperature goals." It is unlikely that this goal can be reached without substantial penetration of zero emission ships resulting in reductions of all air pollutants beyond what is assumed in the Future_Base scenario in this paper.

2) The use of three years to compute an average of the present situation is not clear. Information regarding the averaging of computed years is given piecewise and the reader is left alone with finding out which emissions and meteorology of which years are used for the different scenario simulations and which output year is compared. Definitely, a table presenting this information in one place would be very helpful. Why was only one year (2016) compared with the future scenarios?

Answer: As suggested we have included a table listing what emissions have been used in the model scenarios. The effects of future scenarios were calculated for all three meteorological years.

3) The non-consistent numbering of sections adds to the confusion: section one starts

with the Introduction, followed by a section 'Experimental Setup' which is not numbered and then beginning with 1.1 Emissions. This should probably be section two and renamed 'Model Setup'.

Answer: The section numbering has been changed.

4) Projections for the future ship emissions are not described and justified in the manuscript. How would the air quality change in future if a higher growth of the ship fleet or non-compliance to the stricter regulations are assumed?

Answer from Jukka Pekka Jalkanen:

We (Finnish Meteorological Inst.) are preparing a separate manuscript for scenario development and we wanted to keep this part of the manuscript relatively simple, because this is a long story of its own. The key idea is that a simple scaling up emissions with assumed annual growth rate will not work for future years if energy efficiency gains, future emission regulations, fleet technology developments and regional rules are not properly covered. In this regard, we have divided the scenario development in three parts, which will operate on different ship types in a different way. The three features listed in the manuscript involve a) energy efficiency developments, b) vessel size development and c) vessel numbers. These three contributions are used linking the shipping sector to global transport demand, which in turn is linked to annual GDP growth of various regions in the world.

Efficiency gains for various ship types are obtained from Kalli et al. (2013) (see reference in paper). Vessel numbers of each ship type are based on number of ships built each year. For some vessel types this is very challenging, like for the global containership sector, which has undergone a rapid growth since year 2000. The future shipping fleet is difficult to predict, because for example plotting the number of containerships built each year leads to almost exponential growth which cannot be followed for the next 30 years. In 2050, the number of containerships fleet is assumed to grow by 40%, to 6500 actively used ships. Also, the size development of vessels in various

shipping sectors needs to be considered. The largest Triple E class of container ships in 2014 were able to carry over 18Âă000 TEUs, but 22Âă000 TEU capacity was nearly achieved in 2017. The triple E class has DWT/TEU ratio of almost 11 tons/TEU, which leads to significantly larger vessels if the current DWT growth trend continues. Containership which exceed 50Âă000 TEUs could be introduced to the fleet by 2050 with our assumptions, which is a decade sooner than anticipated in some recent estimates (McKinsey Group, 2017). These vessels will not be operated in the Baltic Sea because of several limitations.

Specific Comments:

1.) P. 2 line 30: Please add a discussion on emissions from open loop scrubbers to air and to water in the Introduction. Moreover, the different alternative fuels and control technologies to fulfil the stricter ECA regulations and their actual use by the BAS ship fleet needs to be addressed. From 2014 to 2016 only the sulphate fraction of PM was reduced accordingly whereas other components of PM were less affected.

Answer: This discussion is now included in the introduction.

2.) P.3 line 1-2: At the end of the Introduction, it is referred to two papers in preparation which are based on results of this study. This reference somehow weakens the scientific relevance of the present study. Either delete or move to the Conclusions.

Answer: These references have been moved to the conclusions

3.) P.3 line 8-9: ECLIPSEv5a: how high is the expected variability of land-based emissions between 2014 and 2016?

Answer:

In this paper we use the ECLIPSE emissions available only on 5 year intervals.We then apply the same Eclipse emissions for all three meteorological years. We use the ECLIPSE emissions in order to get consistent available emissions for both present and 2030 conditions.

However, annually reported emissions for all countries in Europe are listed in the EMEP reports (reference added in the paper). We have added the following text in the paper:

"In reality land based emissions will change between years. Annual emissions from year 2000 to 2016 for the European countries are listed in EMEP (2018). In the Baltic region reported changes in country emission are small with the exception of SOx emissions in Poland dropping almost 20% from 2014 to 2016."

In the paper we deliberately did not change land-based emissions from year to year in order to isolate the effect of the regulations on shipping.

4.) P.3 line 18: Which fraction of open loop scrubbers is assumed for BAS shipping emissions in 2014 and in 2016? What is assumed about primary particle emissions from open loop scrubbers?

Answer: This information is now included in the paper.

"Globally, during 2014 there were 77 vessels using a scrubber, of which 30% were of open loop, 48% of closed loop and 22% of hybrid type. By 2016 scrubber installations were doubled globally to 155 units. In the Baltic Sea area during 2016, there were 85 vessels operating a scrubber releasing 73 million tonnes of wash water to the sea. Almost all of this (99.8\%) discharge came from open loop operation of scrubbers. "

5.) P.3 line 19-21: Are the total BAS shipping emissions for all other pollutants unchanged between 2014 and 2016?

Answer: Ship emissions of other species differ between 2014 and 2016, but much less than for sulphur.

The following text is now included: "Ship emitted pollutants were modelled using AIS data for year 2014 and 2016. Any changes in vessel activity, fleet size and development will have an impact on energy use and all pollutant emissions. However, the sulphur rule was the only significant change which had a large impact on emitted pollutants. Both PM and SOx were reduced by this change, but only the sulphate fraction of PM

was reduced accordingly whereas other components of PM were less affected."

6.) On P.3 line 17, daily emission grids are introduced. On the same page, line 30-31 it is stated that hourly data was aggregated into monthly ship emissions. The purpose of the daily emission grid remains unclear. How high is the uncertainty of monthly versus hourly emissions when considering the titration of ozone by ship emissions?

Answer: We have corrected the text from daily to hourly. Previously we have run the model with daily ship emissions resulting in only small changes hardly affecting the model validation at measurement sites.

7.) P.4 line 6-7: Add reference or delete the sentence on ecosystem specific deposition.

Answer: Moved to conclusions. References included here.

8.) P.5 line 16-23: What is the criterion in this study to conclude that measurements are reproduced by the model, either with or without including ship emissions in the model simulations? The present assessment could be strengthened by use of a quantitative indication for the match between model and measurements.

Answer: A quantitative indication is given in Table 1 in the form of correlation, rmse and now also bias. There is no commonly accepted threshold for when a model performs well, and it is clear that models (and also emission inventories) often have problems in reproducing a short-lived species such as NO2 correctly. But the point with this paragraph was that the (mainly negative) biases in the model become considerably worse (more negative) at all measurement sites when omitting the ship emission source. This is a clear indication of the importance of the ship emission source of NOx at these coastal sites. Likewise for SO2 the positive bias becomes very large for the sites listed when the 2016 emissions are replaced by 2014 emissions in the Baltic Sea. For secondary species (SO4 and PM2.5) and depositions of oxidized N and S the effects of shipping is smaller, and we can't draw any conclusions from the match between model and measurement alone with regard to the effects of Baltic Sea emissions.

9.) P. 6 line 1-2: What is the fraction of sulfate in the modelled PM2.5 in 2014 and 2016? If possible, add a comparison of measured and calculated SO4 at the monitoring stations in Table 1.

Answer: SO4 now included in Table 2

We have also included some additional text here to explain the results: In Table 2 we also show measured and model calculated concentrations of SO4. At the sites in Table 2 both the measured and model calculated fraction of SO4 in PM2.5 is about 0.15, and fraction increase only marginally with the Present_HiSulphur scenario.

10.) P. 7 line 1-2: The small national contribution of ship emissions in countries with large in-land area does not really reflect the local significance of this sector. It would be better to calculate the average value in the coastal zone of the countries.

Answer: In this paper we have used similar methodology as used in the source-receptor calculations in the annual EMEP reports (https://www.emep.int/mscw/mscw_publications.html). In the paper the effects along the Baltic Sea coast is also shown in Figures 1 and 2. In the Barregård et al. paper now submitted to IJERPH population weighted concentration are used.

11.) P. 8 line 8: Does the statement about unaffected emissions of non-sulphur particles hold in view of realistic emissions from open loop scrubbers and the PM emissions from burning ultra-low sulfur heavy fuel oil (HFO)? The use of scrubbers might capture a large fraction of PM, not only sulfate.

Answer: We have added a section in the conclusions discussing this:

"For other species of PM, like EC, OC and Ash, emission factors will be similar as with HFO and thus emissions of non-sulphur particles from BAS shipping are assumed to be virtually unaffected by the SECA regulations.

12.) P. 8 line 20: What is the health impact of negative SOMO35?

Answer: Decreases in SOMO35 (caused by increased NOx resulting in ozone titration) should have a positive health impact. However, the corresponding increase in NOx will, as we demonstrate in the paper, increase PM2.5. As PM2.5 has larger effects on health than ozone the net health effects from NOx should still be negative.

Technical Corrections:

P. 5 line 6: The lifetime of NO2 is relatively short.

Answer: Changed to relatively short.

P. 7 line 19: Please replace “show” by “shown”.

Answer: This part of thext is changed as a result of comments from reviewer 3.

Figure 1 and Figure 2: Please add annotation of x- and y-axis (degrees longitude and latitude) around the concentration maps. The plot header lines are partly cut off and not visible.

Answer: Figures 1 and 2 changed as requested. Figure 2a showed total (oxidised + redused) depositions of N. Corrected to oxidised N.

Figure 3: For some countries the green and red bars are hardly visible. I suggest to add additional plots where the contributions from BAS and from high-sulphur fuel are enhanced.

Answer: Instead of making additional plots we have added the values for the small "Add Baltic" and "Add Baltic 2014" as numbers behind the bars. We have also changed the colour codes to make the text more visible. We believe that these changes make the charts more readable.

Figure 4: In figure part (a) cut the x-axis in the plot at 2000 ppb days and add the values for the bars above 2000 inside the plot.

Answer: We have added the values for the smaller red and blue bars inside the plot.

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