

Revisions in manuscript:

Present and future variation of Contribution from Ship Emissions to the concentration and deposition of air pollutants in the Baltic Sea

Authors

We have changed the order of the authors as

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Abstract

This part is completely rewritten and changed by emphasizing the scenario parts and to present an overview of the spatial pattern and comparison to measurements. Most specific numbers are condensed.

Specific comments on reviewers' remarks

- Most specific numbers are condensed because of the uncertainties in extreme values

1. Introduction

This part is more or less completely rewritten. First paragraph is left slightly changed while the rest is partly re-arranged for the line of thought and partly renewed to shift the focus towards the scenarios. We also present more thoroughly the study of Jonson et al. (2015) and point out the novelty of the present study and that we will compare our results to theirs regarding effect of model resolution and nitrogen scenarios.

Specific comments on reviewers' remarks

- The Scope is clarified together with the novelty
- Jonson et al. (2015) study is presented in more detail and so is our relation to that work, with comparisons regarding concentration and deposition patterns
- NECA is discussed and is implemented in the scenarios and analysis
- Also the 0.5% S in global EU fleet is discussed

2. Data

In this section clarifications and rearrangement are made. The names of the subsections are now EMEP model system, EMEP model data, Other data sources and Measurements.

Specific comments on reviewers' remarks

- Data and report content description is expanded.
- Model versions rv.4.4 and rv.4.8 is compared

2.1 EMEP model system

Model performance evaluation by Gauss is moved here from (old section 2.3).

2.2 EMEP model data

Text is somewhat expanded to clarify. Also the differences between model versions rv.4.4 and 4.8 are shown (also with figure).

- Added new figure:
 - Difference (in %) of deposition from EMEP model rv.4.4 to rv.4.8 for a) oxidized sulphur and b) oxidized nitrogen.

2.3 Other data sources

This is a new section that presents data from emission databases and results from the MATCH model, used for the background deposition scenarios in the future.

2.4 Measurements

The old “model performance” section is renamed to “measurements” to present only the Vavihill and Utö concentration data.

3. Methods

This is the renamed methodology section. We changed some wording of the section headers and added a section “Model performance of concentrations”.

Specific comments on reviewers’ remarks

- The reason for the use of different model version is presented
- The method is presented more in detail
- Line of thought is improved

3.1 EMEP Model Runs

This part is rewritten to clarify why the two versions of the EMEP model is used.

3.2 Model performance of concentrations

This part consists of parts from old section 2.3 (Model Performance, related to the comparison of simulated and observed concentrations).

3.3 Future Ship Emissions

Apart from some minor wording changes, the last paragraph about sulphur reduction is removed. We also inserted a sentence about NECA.

3.4 Deposition scenarios of ship emissions

Here we made the text clearer.

4 Results

We have restructured this section more or less completely. Some figures and tables are added.

4.1 Ship deposition scenarios

Text is very much expanded because of a deeper analysis. First we present the distribution of ship emission and associated deposition in the base year. Also the associated seasonal variation of the ship deposition in different Baltic Sea basins are presented.

Then the emission and scrubber scenarios are presented and discussed, to be followed by the estimated deposition scenarios from ship traffic and also related to other sources. Totals for the whole Baltic Sea area is presented as well in a table. The outline for the deposition is the separation between oxidised sulphur and nitrogen, with the former presented first. For the nitrogen first the original data is presented and then the influence from NECA is implemented. The proton input (2 for S and 1 for N in $\text{nmol m}^{-2} \text{yr}^{-1}$) in the Baltic Sea basins is estimated for the different scenarios. Last a correction factor is also calculated to convert rv.4.4 results to rv.4.8 results. However, the impact is estimated to be small, at the larger scale, and not used.

Specific comments on reviewers' remarks

- New calculations with NECA
- 0.5 % S in fuel globally is discussed

Scenario figures with monthly resolution are replaced by annual resolution with relative monthly changes in a separate figure.

New figures:

- Total emissions of SO_2 and deposition of OXS from international shipping in the Baltic Sea and North Sea in 2011.
 - Partly new
 - replaces partly old fig. 5 and fig. 8
- Monthly deposition of oxidized sulphur (OXS) in six basins.
 - New
- Annual ship deposition of sulphur (mgm^{-2}) in six basins
 - Replaces the monthly data in old fig. 10
- Annual deposition of sulphur from all emission sources (gm^{-2}) in six basins of the Baltic Sea year 1900 to 2050.
 - Replaces the monthly data in old fig. 11
- Annual ship deposition of nitrogen (gm^{-2}) in the basins of the Baltic Sea, year 1900 to 2050.
 - Replaces the monthly data in old fig. 12
- Annual deposition of nitrogen from all emission sources (gm^{-2}) in the basins of the Baltic Sea year 1900 to 2050.
 - Replaces the monthly data in old fig. 13
- In a) estimated part of fleet applying to TIER I (blue), TIER II (red) and TIER III/NECA (orange), in b) correction factor for OXN deposition from shipping, using the implementation of TIER II and the TIER III in NECA from 2021.
 - new
- Annual proton input from OXS and OXN in the basins of the Baltic Sea (defined in Fig. 2) for year 2010 to 2050. The red line corresponds to Shipping scenario 3, the magenta and cyan line to Shipping scenario 4 and 5, respectively (scrubber + atmospheric deposition). The black line shows historical shipping (derived in Omstedt et al., 2015). Green and blue lines is with implantation of TIER II and NECA and scrubber scenario 4 and 5, respectively.
 - new
- Correction of deposition caused by ship traffic, in the different Baltic Sea basins.
 - new

New tables:

- Total deposition of OXS and OXN in Baltic Sea Mg yr⁻¹.
 - New
 - Partly replaces fig 14-15
- Emissions from shipping in the Baltic Sea in Mg yr⁻¹.
 - new

4.2 Present emissions and surface concentrations

This section replaces old section 4.1 (Surface concentration) and adds discussion of present emissions.

The concentration validation table and figures are moved to an appendix.

New figures

- Annual mean concentration of near-surface concentration (at 3 m level) of particulate matter from all emission sources in the EMEP area, in upper panel for rv.4.4 and in lower panel in rv.4.8.
 - new
- Percentage (%) of the total surface concentration, caused by international shipping in the Baltic Sea and the North Sea in 2011
 - New colorbar
- Concentration of PM_{2.5} caused by shipping
 - New colorbar

4.3 Present Deposition

This section replaces old section 4.2 (Deposition). It analyses the simulated deposition in 2013. Text is re-arranged to more clearly follow the line of thought. Some comparison is also made with Johnson et al. (2015).

- Deposition of a) OXS and b) OXN caused by shipping.
 - Replaces old fig. 8
- Percentage (%) of the deposition, caused by international shipping in the Baltic Sea and the North Sea in 2013 of- (a) Dry OXN, (b) Dry OXS, (c) Wet OXN, (d) wet OXS.
 - Replaces old fig. 9

5 Discussion

This section is expanded and re-arranged to get a clearer line of thought. First we discuss emissions, regulations and the potential effect of using scrubbers on acidification. Then we turn to uncertainties with ship emissions, the methods used regarding resolution of the model and statistical approach. Last some aspects interesting for future studies are discussed.

6 Summary and Conclusions

This section is expanded regarding the scrubbers and scenarios. The section ends with conclusions in bullet form.

References

Specific comments on reviewers' remarks

- The text books Arya and Raven & Berg are completely removed.
- The other errors are corrected

Figures and tables

Specific comments on reviewers' remarks

- Tau correlation is removed from the (old) table 2.
- The figure colour bars are made simpler to read.
- Units and headers are updated
- The PM10 is not trespassed at all, and PM2.5 is trespassed only in the Benelux area, also now mentioned in the text, but not shown in the figure.

Appendix: Concentration validation at Vavihill and Utö