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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Multi-model simulations of the impact of international shipping on atmospheric chemistry and climate in 2000 and 2030" *by* V. Eyring et al.

V. Eyring et al.

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We would like to thank the reviewers for their constructive and very useful comments and suggestions. We have considered carefully each of the comments in the revised manuscript. Detailed answers to the reviewers'comments are given below.

1 Summary of most important changes

Both reviewers requested a more detailed evaluation of model results with observations and in particular recommended to include a comparison with in situ data in

addition to the presented comparison to satellite measurements from SCIAMACHY. We considered this in the revised manuscript and have included a new section 3.1 called “Comparison of model results with observations”. The focus of the additional model evaluation with in situ observations is on the models’ ability to simulate ozone, NO_x and SO_2 in the marine boundary layer. The comparison with SCIAMACHY data has been moved to this sub-section.

The other major issue that has been raised by reviewer 1 was the neglect of CO and VOC emissions from ships in the model simulations. The reviewer claims that this is a crude simplification, which limits the importance of the outcome and conclusion of the model exercise. With the help of additional sensitivity simulations carried out by one of the participating models (MATCH-MPIC) with VOC and CO emissions from ships included we show that changes compared to the reference simulations are very small and that the neglect of ship CO and VOC emissions in the reference simulations does not change the main conclusions of this paper.

2 Response to Reviewer #1

a) Plume chemistry

We think that the plume chemistry paragraph is an important paragraph, but present it in a more general context in the revised version and have significantly shortened it, as suggested.

b) Non-linearities

Firstly, as we have already mentioned above, our neglect of ship CO and VOC emissions has very little impact on our findings. Secondly, we must be absolutely clear: the models describe atmospheric photochemistry in considerable detail,

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and include multiple non-linear interactions. Of course, this doesn't mean we should necessarily expect non-linear relationships in our results. Indeed, the response of the modelled NO_x and O_3 burdens to varying the magnitude of ship NO_x emissions is basically linear (Figure 9). This is no great surprise, as past global modelling studies (e.g. Stevenson et al., 1998; Stevenson et al., 2006) have found that the troposphere is mainly NO_x-limited with respect to O_3 production, as is to be expected since the vast majority of it is quite remote from NO_x emissions. This is particularly true for oceanic regions, i.e. where the ships are emitting. VOC-limited O_3 production regions are typically limited to highly polluted, urban areas; these rarely occur, even in the most congested shipping lanes, at least when they are represented in global model grid-boxes. In short, we do not deliberately simplify our results to give a linear relationship – it just exists – and it is broadly what we expected.

c) Emission effects in the Baltic Sea region

Ship emission inventories are subject to considerable uncertainties (see Eyring et al., 2005a,b and Section 4.1.1). In our study, we used the ship emissions from the EDGAR3.2 database. We consider the EDGAR3.2 data to be the best available for global scale anthropogenic emissions, and is one of the few available ship inventories. As discussed in the paper, we used this particular emissions dataset for two reasons: (a) we wanted to retain consistency with other anthropogenic emissions, which also used EDGAR3.2 (see Section 2.2) and, (b) we do not account for sub-grid scale ship plume processes; hence we have chosen a low ship emission estimate (see section 4.1). We agree that the EDGAR emissions might overestimate emissions over the Baltic and underestimate emissions in the Mediterranean region (see e.g. Section 4.1.1).

d) Figures 6 to 8 (Figure 9 and 10 in revised version)

We have changed Figures 9 and 10 in the revised version so that labels are now

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consistent with Table 1 and text and also changed the colors. Figure 6 has been combined with Figure 10 as suggested.

e) Saturation effects

Although Figure 7 (Figure 9 in revised manuscript) demonstrates the response of NO_x and O_3 burden to ship NO_x is broadly linear, there are some slight 'saturation' effects (i.e. deviations from linearity) that can be seen in the O_3 burden response in Figure 9. In other words, the gradient between the origin and the first point is slightly steeper than the gradient between the first and second points; this is true for each model. The NO_x burden response shows no significant deviation from linearity for all models. Figure 9 has been improved so that this is more visible.

f) Specific comments Reviewer #1

Abstract:

- *Mentioning of the anthropogenic emissions (page 8555, line 29) already before (page 8555, line 8)*
  Changed as suggested
- *A statement of the importance of the effect from ship emissions on climate and air pollution relative to other sources is missing.*
  The abstract does include a measure of the contribution of ships to projected O_3 and SO_4 changes between 2000 and 2030: "Globally, shipping contributes 3% to increases in O_3 burden between 2000 and 2030, and 4.5% to increases in sulphate under A2/CGS. However, if future ground based emissions follow a more stringent scenario, the relative importance of ship emissions will increase."
- *NO_x enhances OH? Simplification → isoplethen diagram*
  'over the remote ocean' added

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- *IPCC SRES A2 not explained, avoid abbreviation in the abstract*
  Changed as suggested

1. Introduction:

- *international shipping: some explanation or definition would be helpful, e.g. are harbour emissions included?*
  A definition of the emission inventory is given in section 2.
- *It should be mentioned that also BC and OC aerosols from ship emissions impact on climate*
  A sentence on the possible impact of BC and OC emissions has been added to the introduction.
- *The missing NMHC and CO emissions should be mentioned*
  'how emissions for international shipping' changed to 'how NO_x and SO_2 emissions from international shipping'
- *Page 8557, line 2: too strong statement: The models overestimate the observed NO_x distribution for example over the Atlantic, but underestimate SO_2 observations. This sentence is misleading without further explanation and out of context, because it is not generally true.*
  Changed
- *Page 8557, line 6: again too strong statement, better: one possibility for the discrepancy between measured and modelled*
  Changed as suggested
- *Page 8557: SO_2 is not at all independent on plume chemistry. Chimney emissions from fossil fuel burning contain enough water vapour that condenses pretty fast and present an ideal environment for aqueous phase reactions, e.g. SO_2 oxidation in particular in the humid marine boundary*

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layer. Sulfate formation and the indirect aerosol effect mentioned in the next sentence of the paper prove that.

Changed to 'enhanced OH in the plume'

- *Page 8558, line 10: what is meant by ship modifications? Here it could be mentioned that ship engine are usually much longer in use than car engines are and therefore of old technology.*

  The Eyring et al papers (2005a,b) are cited where this is addressed in detail.

- *Page 8558, line 22: needs to be: too strong, better: which can be*

  Changed as suggested

- *Page 8559, line 13: add roughly: RFs due to CO_2 and sulphate are roughly estimated*

  Changed as suggested

2. Models and model simulations

- *Page 8560, line 11 paragraph: in addition dry and wet deposition, vertical and horizontal diffusion and transport in convective clouds are treated different in the models; mentioned later on page 8564/8565, could be deleted there and mentioned here*

  Changed as suggested

- *CO emissions from ships small? Why?*

  In general, CO emission is the result of incomplete combustion. Since large-bore diesel engines operate at high air excess ratios and high combustion temperatures, carbon monoxide emissions from diesel engines are much lower than from other internal combustion engines (has been added in section 4.2.2.)

- *page 8563: what is the additional available information to interpolate up to 5°x5° data to 0.5°x0.5° data?*

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Interpolating the data to a 0.5°x0.5° grid allows us to maintain the full information on the geographical patterns provided by each model when re-gridding the model data to a common grid. The high resolution of 0.5°x0.5° prevents aliasing and smearing effects which might occur if the common grid had a similar resolution as the original model grid but a different definition of location and exact size of the grid boxes.

3. Results

- *Page 8564, line 15: slightly different background emissions? What is meant? Do the models not use the same emissions inventories for anthropogenic and natural emissions? If not, a reference to another paper is not sufficient, some explanation in section 2.2 is necessary.*

  Models used the same anthropogenic and biomass burning emissions, but used variable natural emissions. For example, for NO_x, natural sources from soils and lightning differ between the models, but this has little impact over the oceans. For SO_2, natural sources from volcanoes and oceanic DMS differ. The latter has some impact on absolute values of SO_2 over the oceans, but little impact on changes due to ships. The differences in natural emissions are not thought to be a major source of inter-model differences in the results presented here. Sub-sentence has been removed and a sentence on the difference in the emissions has been added to section 2.2.

- *Page 8564, line 18: 'Previous studies reported that the production of ozone depends on the resolution of the model with models having higher resolution simulating less ozone production than those with a coarser resolution.' This statement is out of context and not at all right in general.*

  One of the models used here (FRSGC/UCI) has looked at the issue of model resolution is some detail (Wild and Prather, 2006), with the main finding that an increase in model resolution caused a slight reduction in global ozone

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production. Other modelling studies (Liang and Jacobsen, 2000; Esler, 2003) indicate similar conclusions, so we suspect this is universal.

- *Page 8565, from line 25: 'In July NO_2 changes are in general slightly smaller than in January and cover a smaller area.' This holds only for the Baltic Sea region and the adjacent countries. Here the uncertainties of the emission inventory need to be mentioned.*

  Changed as suggested.

- *In the following sentences it is not clear what is meant with high NO_2 background concentrations over the Baltic Sea, they seem to be due to the coarse model resolution, but do not reproduce what is observed. Comparison with measurement data, e.g. station measurement from EMEP would be helpful. Mention uncertainties, like that shipping on the frozen Baltic Sea in winter time is overestimated due to the yearly average emissions inventory and put the importance of the results into a more realistic picture.*

  'Background conditions' has been changed to 'level of NO_x from other sources.' We agree with the reviewer that the Baltic effect might be overestimated due to the inventory that is used and discuss this in Section 4.1.1. We made this uncertainty again clearer and added the uncertainty due to the use of yearly average emissions to 4.1.1.: "In addition, the use of a yearly average ship emission inventory is a simplification and e.g. overestimates the impact of ship emissions over the partly frozen Baltic Sea in winter time."

- *Page 8568, line 25: 'Over Northern Europe relatively low levels of insolation (even during summer)'. If the hours of sunshine are meant, than the sentence is certainly not right.*

  Removed

- *Page 8571, line 5: replace oxidised by oxidation*

  Changed as suggested

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- *Page 8571, line 10: such as sea salt, BC or OC*
  Changed as suggested
- *Page 8571, first paragraph: too much introduction, either leave it out or add it somehow to section 1: Introduction*
  Changed as suggested
- *Page 8571, second paragraph: mention that zonal means are presented*
  Changed as suggested
- *Page 8572, line 5: 'In all other parts of the world, changes in sulphate due to emissions from shipping remain low in general'. Again the uncertainties of this result should be mentioned, a potential overestimation of the Baltic Sea effect and a potential underestimation of the Mediterranean effect, where dry weather conditions favour the accumulation of 'pollutants' during summer.*
  Uncertainties in the Mediterranean have been added to section 4.1.1.
- *Section 3.4, first paragraph: rather unclear, either more explanations (e.g. wavelength intervals considered, how are clouds considered, what is meant by stratospheric temperature adjustment, what means instantaneous in this context?) of the off-line radiative transfer model are necessary or all details should be skipped.*
  Reworded for clarification. Details are given in Stevenson et al. (1998).
- *The reference to Edwards and Slingo (1996) is missing in the reference list. Avoid the word 'code', which is rather technical.*
  Reference added and 'code' replaced by 'scheme'.
- *Page 8574: first paragraph, last two sentences: not clear without more explanation; unnecessary, can be deleted*
  Changed as suggested

4. Discussion

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- *Page 8575, first sentence: add NO_x and SO_x and for 2030 emission conditions without considering possible change in atmospheric temperature, dynamics, humidity etc.*

  Changed as suggested

- *Page 8577, first paragraph: discuss the use of NO_x and SO_x ship emissions only without CO and NHMC emissions from ships on the oxidizing capacity of the atmosphere*

  A subsection has been added that discusses the neglect of CO and VOC emissions (see above)

3 Response to Reviewer #2

a) Recommendation for future observations and model improvements

A paragraph has been added to the final section that gives recommendations for the location and type of future in-situ measurements, which may help evaluate global model simulations of ship emission impact. The need to develop innovative parameterization for sub-grid scale processes in ship plumes has also been included in this paragraph.

b) Difference between the model predicted NO_x due to the model grid size difference

An increase in model resolution caused a slight reduction in global ozone production in Wild and Prather (2006). A quantification of the difference due to model grid size difference is beyond the scope of this study as it would require simulations from all participating models with varying resolutions.

c) Specific Comments Reviewer #2

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- *Page 8565-8566: Would the model meteorology difference have some effect on the predicted vertical distributions of NO_x? The authors should consider expanding their discussion on the differences in model meteorology.*

  Differences in model meteorology should result in differences in the calculated vertical distribution of trace gases. We agree that this is an additional source of uncertainty, but we expect this to be a second order effect only. The differences in the model physics and the different treatment of the relevant processes are more important.

- *Page 8569, line 18-19: The saturation effect is NOT visible to this reviewer.*

  We changed Figure 7 (Figure 9 in revised manuscript) so that the saturation effect is more obvious.

- *Page 8595: Figure 2 label is not completely consistent with the model list in the text. This reviewer can not find the UIO_CTM2 model results. The authors should check other figures and make the labels and text consistent.*

  Changed as suggested

- *Page 8600 and 8601: something needs to be done on Figure 7 and 8. It is very difficult to tell the difference in some of the colors. For Figure, the authors may consider put on larger legend instead 8 small ones. It is very very difficult for this reviewer to read the legend*

  Changed as suggested

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 8553, 2006.