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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Atmospheric deposition of nitrogen to the Baltic Sea in the period 1995–2006" *by* J. Bartnicki et al.

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We would like to thank the Referee2 T. Dore for the detailed review of our manuscript and useful and important comments and corrections. We reply, to general comment and to each specific comment, quoting these comments first.

General comment:

The main issue which I think needs attention is some inclusion of validation of the model with measurements or reference to such a study. Subject to a response to this point, I am pleased to recommend the paper for publication in its present form.

Reply:

This important point has been already mentioned by the first Referee, so our reply will be similar here. The EMEP model is systematically verified every year on the latest available measurement data and this was the reason why we slightly limited the scope of this subject in our manuscript. In addition, there has been a study (Fagerli and Aas, 2008) focused on comparison of modelled and measured nitrogen in air and precipitation in the long term period 1980-2003. Altogether 33 EMEP sites located in different parts of Europe were used in this study which indicated a decline of ammonium and nitrate in precipitation both in measurements and model results. However, out of 33, only 5 sites reported concentration in precipitation in the locations close to the Baltic Sea basin. Therefore, we decided to expand the subject of model verification in the revised manuscript and include the results of additional research. Thanks to Wenche Aas from the Norwegian Institute of Air Research, we have received the data with measured nitrogen concentrations in precipitation at so called HELCOM stations, which are in fact the EMEP stations reporting in slightly different way for the HELCOM purpose. We have examined 21 HELCOM sites, of which 11 reported annual nitrogen concentrations in precipitation and precipitation amount for the entire period 1995-2006. We have used the 11 stations with data available over the entire period for comparing observed annual wet deposition with the modelled wet deposition. In addition, annual precipitation amount to the Baltic Sea basin is also compared as average from measurements over 11 stations and average over all model grids covering Baltic Sea basin. This comparison is shown in Fig. 1. For all stations there is a relatively good agreement between average observed and modelled deposition values over the entire period, but the correlation is not so good, mainly because of differences in modelled and observed precipitation amount for individual stations. This good agreement indicates that the most likely, additional reason for the differences in nitrogen deposition to the Baltic Sea basin calculated by the EMEP model and by the MATCH and ACDP models is related to different emission inventories used for the calculations. Both nitrogen and sulphur emissions were slightly lower in the EMEP calculations after latest revisions in 2010. However, different meteorology still remains an important factor for the differ-

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ences. The inter-annual variation of measured annual nitrogen deposition is similar, but larger than the inter-annual variation of modelled deposition. However, correlation between annual measured and modelled values is not very good, typically around 0.3 and this is a follow up of a bad correlation between measured and modelled annual precipitation. The modelled precipitation comes from the numerical weather prediction model and represents the entire grid square, whereas the realistic variation of precipitation within one grid square is high. In some cases it can be higher than 100% (e.g. model grid square which includes Bergen in Norway). When the model wet deposition is calculated with precipitation from the station, the correlation between measured and modelled deposition is much better, above 0.8. The examination of data behind Fig. 6 show that the reduction in modelled wet deposition in the period 2001-2006 compared to period 1995-2000 is 13%. Similar reduction is present in the measured deposition for the stations in Fig. 1 Except for two stations DK05 Keldsnor and PL04 Leba, there is a clear reduction for measured wet deposition in the period 2001-2006 - on average 10%. This value is quite similar and only slightly lower than predicted by the model calculations. The above discussion and Fig. 1 are included in the revised manuscript.

Specific Comment:

Introduction: "The nitrogen input entering the Baltic Sea is both airborne and waterborne, whereas phosphorus input is mostly waterborne (HELCOM, 2010). Atmospheric deposition of nitrogen accounts for approximately one quarter to one third of the total nitrogen load to the Baltic Sea (HELCOM, 2005a)" This suggests that two thirds to three quarters of nitrogen entering the Baltic Sea is waterborne. Presumably this contribution will also have decreased as emissions have gone down, though this may depend on the response of soil to nitrogen deposition. Can the authors refer to any studies which estimate how this input may have atmospheric modelling study?

Reply:

Thanks to the Referee for raising this point. We have tried to be more specific on this issue and the results of our search are summarized in Fig. 2. The calculations presented in Fig. R2.2 are based on the waterborne data available in Wulff et al. (2006). Typically the airborne contribution is a quarter to one third of the total load. However, there are large inter-annual variation in airborne contribution to nitrogen load, with minimum - 27% in the year 2002 and maximum – 47% in the year 2000, significantly exceeding the typical range. In the year 2000 dry and wet deposition of nitrogen from the air is reaching maximum for the entire period, whereas the riverine load is at the minimum for the same period. The above comments, as well as Fig. 2 and the reference are included in the revised version of the manuscript.

Specific Comment:

Introduction and section 2: "Under normal operation, the EMEP model is frequently improved and changed, almost every year and often different model versions are applied for calculating transport and deposition in different years. The same applies to meteorological data, which can be provided by different Numerical weather Prediction 15 models in different years. By selecting the 1995–2006 period, we managed to avoid this kind of problems in the present study." This is an important statement and demonstrates the difficulties associated with applying atmospheric transport models to assessing environmental responses to changes in pollutant emissions. The same could also be said of emissions estimates. Techniques for inventories and spatial mapping of emissions have also changed significantly during the period of a decade and a half. How did the study account for this?

Reply:

Concerning emission inventories necessary to run the model for the considered period, we were fortunate to use the latest available emissions available from CEIP revised in 2010 for the entire period of the simulation. In this way we were able to avoid the changes and updates in emissions, which normally happen almost every year and use a consistent set of emission input for the model run.

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Specific Comment:

The validity of any atmospheric transport modelling study relies on the model having been compared with measurements. These results are not included here. Certainly the EMEP unified model has been extensively validated against measurements. I don't think a detailed validation against measurements is required here but some reference to or summary of such a study for nitrogen compounds should be included.

Reply:

We have discussed this problem already when replying to the first general comment.

Specific Comment:

The standard computational domain of the EMEP model is shown in Fig. 1 together with slightly smaller domain which was used for calculations presented here. The Baltic Sea Basin is located in the centre of reduced model domain, which is large enough for 20 the estimation of nitrogen deposition and source receptor allocation for the Baltic Sea basin. I suggest to state the model grid resolution and number of x and y grid points here." Fig. 5. Calculated annual deposition to the Baltic Sea basin of: dry oxidized, wet oxidised, dry reduced and wet reduced nitrogen in the period 1995–2006. Units: Gg Na-1. Units: should be: Gg N Ha-1.

Reply:

The following sentence is included in the revised version of the manuscript: The size of the standard model grid is 170×133 nodes and its resolution is 50 km in Polar Stereographic Projection at 60 deg N. Concerning Fig. 5, the correct unit for annual nitrogen deposition to the entire Baltic basin should be: Gg N per year and this unit is used in the revised version of the manuscript.

Specific Comment:

Page 1812: A large inter-annual variability can be seen in oxidised wet and reduced wet

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deposition, whereas, inter-annual variability in oxidised dry and oxidised wet deposition remains relatively low. This should be : : : oxidised dry and reduced dry deposition : : : Page 1812: In this case, other than precipitation, meteorological factors like annual patterns of wind direction, mixing height and temperature play an important role in the deposition. Can the authors be more explicit here? Perhaps greater large scale advection of air from high emissions areas in the south of the study is responsible? Conclusion: The average, over the period 1997–2006 contribution of Germany, United Kingdom and Poland and Denmark to total nitrogen deposition into the Baltic Sea basin is 20%, 12% and 10%, respectively. Should this be : : : Germany, Poland and Denmark : : : ?

Reply:

The first sentence has been corrected in the following way: A large inter-annual variability can be seen in oxidised wet and reduced wet deposition, whereas, inter-annual variability in oxidised dry and reduced dry deposition remains relatively low. Concerning other meteorological factors influencing deposition, we would like to thank Referee for a good suggestion. A relatively large contribution of Germany to total nitrogen deposition into the Baltic Sea basin in the year 1999 and 2000 suggests that the atmospheric transport from the regions with high nitrogen emissions can be also responsible for the deposition maximum in the same year. This sentence is included in the revised version of the manuscript. The sentence in the conclusion has been corrected in the revised version of the manuscript in the following way: The average, over the period 1997–2006 contribution of Germany, Poland and Denmark to total nitrogen deposition into the Baltic Sea basin is 20%, 12% and 10%, respectively.

Specific Comment:

Conclusion: There is also a systematic increase of contribution from the international ship traffic on the Baltic Sea from 4% in 1997 to 5% in 2006. Presumably this is due to increasing international shipping traffic (and oxidised nitrogen emissions) whilst

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emissions from land have fallen. Can some comment be made on changes to shipping emissions? Perhaps these emissions could be included in Table 1?

Reply:

Annual nitrogen oxides emissions from the international ship traffic on the Baltic Sea for the period 1995-2006 are included in Table 1 of the revised version of the manuscript.

References

Fagerli H. and W. Aas (2008) Trends of nitrogen in air and precipitation: Model results and observations at EMEP sites in Europe, 1980–2003. Environmental Pollution 154(3), 448-461.

Wulff F., Humborg Ch., Medina M.R., Mörth M, Savchuk O. and A. Sokolov (2009) Revision of the country allocation of nutrient reductions in the Baltic Sea Action Plan – Section A: Hydrological adjusted riverine load and atmospheric loads from different countries averaged for 2000-2006. Technical Report No. 1. Baltic Nest Institute, Stockholm University, Sweden.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 1803, 2011.

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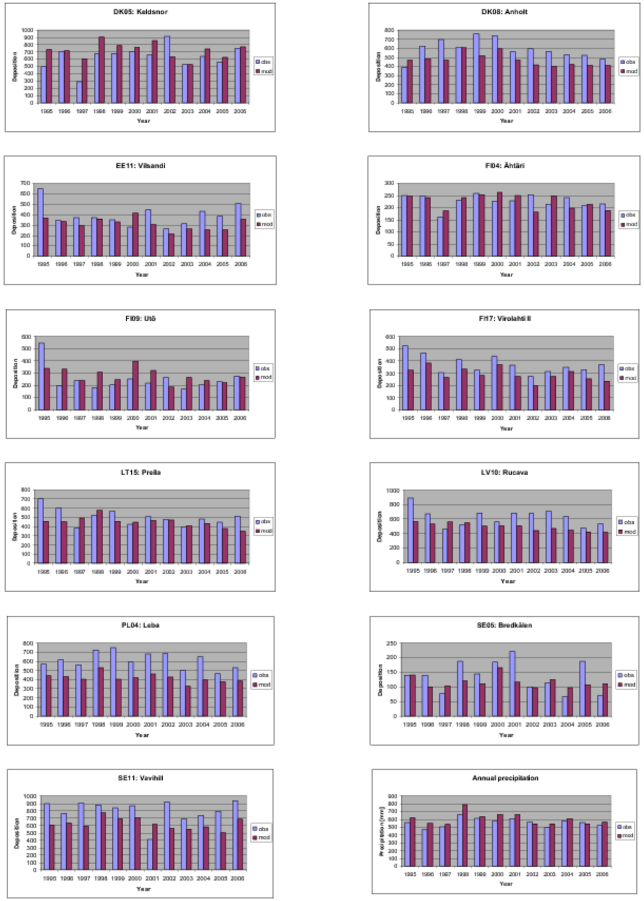

Fig. 1. Comparison of annual wet deposition based on observations (obs) at HELCOM stations and calculated by the EMEP model (mod). Units mg N/m2. Observed and modelled precipitation.

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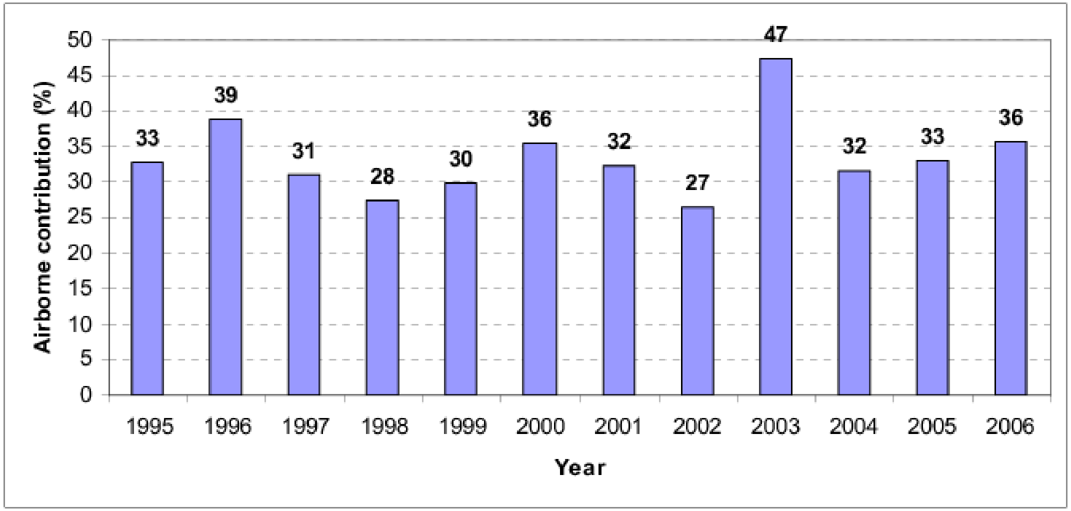

Fig. 2. Annual airborne contribution to total (waterborne plus airborne) load of nitrogen into the Baltic Sea. Units: % of total load.