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Atmospheric Chemistry and Physics Discussions

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Interactive comment

Interactive comment on "Impact of a nitrogen emission control area (NECA) on the future air quality and nitrogen deposition to seawater in the Baltic Sea region" *by* Matthias Karl et al.

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We thank Referee #2 for positive evaluation of the manuscript. Following the Reviewer's remarks, the evaluation parts on precipitation and nitrogen deposition have been substantially condensed in the revised manuscript. We have addressed the issues brought up below, with specific pointers to changed parts of the manuscript.

1. My main comment is that the paper is quite dense with 13 tables and 14 figures, mostly multi-panel ones. While I acknowledge the efforts made by the authors to be thorough, some of the materials are better suited in the supplementary so that the main text is focused on the key messages. I suggest the following

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Discussion paper

figures/tables and associated texts be placed in the supplementary; these are mostly model evaluations which can be summarized in writing and then refer to specific figures/tables in the supplementary as backups to support the write-up. These are Figure 3 and 4 (precipitation evaluation), Table 3, Table 5 or Figure 5 (both show the model performance of nitrogen deposition; it is sufficient to keep one in the main text), and Table 7-10.

Reply: Figure 3, Figure 4 and Table 3 have been moved to the Supplement. Table 4 (WNO3) and Table 5 (WNH4) together show the evaluation of the wet deposition of nitrogen. Both have been moved to the Supplement. Figure 5 has been kept in the main text because it illustrates the differences between CD16 and CD04 resolutions. Table 7, 8, 9, and 10 have been moved to the Supplement. Figures and Tables have been renumbered accordingly. Associated text has been arranged into three new sections in the Supplement that describe the methodology and results of the evaluation of modelled data with observations: Sect. S1 "Methodology and results for the evaluation of modelled precipitation", Sect. S2 "Methodology and results for the evaluation of modelled wet deposition of nitrogen", and Sect. S3 "Methodology and results for the evaluation of modelled air pollutant concentrations".

2. Introduction: the present write-up does not mention the importance of NOx as a precursor of tropospheric ozone. This should be added, as the paper also presents the effect of shipping emissions on ozone.

Reply: The following has been added on page 1, Line 26: "The atmospheric transformation of emitted NOx from shipping is especially relevant for the formation of ozone (Eyring et al., 2010). Shipping emissions are estimated to play an important role on ozone (O_3) levels compared to the road transport sector near the coastal zone in Europe (Tagaris et al., 2017). A regional impact study by Huszar et al. (2010) found that the contribution of shipping emissions to surface NOx levels causes an increase of surface O_3 by up to 4–6 ppbv over the eastern Atlantic and western Europe. O_3 can damage vegetation, reduce plant primary productivity and agricultural crop yields

(Chuwah et al., 2015) and is also a serious concern for human health (EEA, 2015).”

3. a) Pg6, line 8-14: The writing on the treatment of sub-grid clouds is confusing. First, does the CMAQ model used for the manuscript treat sub-grid cloud or not? The last sentence seems to indicate it does not. If so, then the preceding sentences on the sub-grid clouds should be removed and replaced by a simple statement saying that sub-grid cloud treatment available in the standard CMAQ model is not used.

Reply: CMAQ simulates the presence of both resolved and sub-grid clouds and their effects on atmospheric chemistry. The Meteorology-Chemistry Interface Processor of CMAQ, MCIP, diagnoses for each horizontal grid cell the cloud coverage, cloud base and top, and the average liquid water content in the cloud using a series of simple algorithms based on a relative humidity threshold (Otte and Pleim, 2010). These cloud algorithms are described in detail in Byun et al. (1999). The transport processes in the atmosphere primarily consist of advection and diffusion, except for the mixing of pollutants by the parameterized sub-grid clouds (Byun et al., 1999). CMAQ first determines the presence of resolved clouds (clouds resolved in the output of the meteorological model) based on the total liquid water mixing ratio in each vertical layer. Next CMAQ diagnosis the presence of sub-grid precipitating convective clouds and determines the fractional cloud cover of sub-grid non-precipitating clouds. If the convective clouds are resolved in the output of the meteorological model, the diagnosis of sub-grid clouds in CMAQ becomes unnecessary and should be turned off. In CMAQ v5.0.1., the version used in the present study, the cloud module was updated to only simulate sub-grid clouds when the meteorological driver has used a convective cloud parameterization (https://www.airqualitymodeling.org/index.php/CMAQ_version_5.0_(February_2012_release)_Technical_Documentation). Switching off the sub-grid cloud diagnosis in CMAQ circumvents the known limitations of CMAQ in correctly determining the cloud cover of sub-grid non-precipitating clouds. In the presented simulations with CMAQ v5.0.1, the sub-grid clouds were simulated for the 64-km grid resolution and the 16-km resolution, but not for the 4-km resolution because the convective clouds have been resolved in the output of COSMO-CLM for the high-resolution grid.

To avoid ambiguities, text on Page 6, Lines 8-14 has been revised as follows: "Three types of clouds are modelled in CMAQ: sub-grid convective precipitation clouds, sub-grid non-precipitating clouds and grid-resolved clouds. CMAQ simulates the aqueous phase chemistry in all cloud types. For the two types of sub-grid clouds, the cloud module in CMAQ vertically redistributes pollutants and calculates in-cloud and precipitation scavenging. Since the meteorological model provides information about the grid-resolved clouds, CMAQ subsequently does not apply further cloud dynamics for this cloud type. Sub-grid clouds are only simulated in CMAQ when the meteorological driver uses a convective cloud parameterization. Hence sub-grid clouds are treated by CMAQ on the coarser outer resolution grids (64-km and 16-km) but not on the 4×4 km^2 model domain because the convective clouds are resolved for the fine grid resolution by the meteorological model."

3. b) Second, I am not convinced that the 4km x 4km resolution is sufficiently fine to resolve convective clouds. Do you have references or model simulations to support this?

Reply: Meteorological fields that were used in the CMAQ simulation on the 4×4 km^2 resolution grid are from COSMO-CLM output with a horizontal resolution of 0.025 degree (see Page 3, Line 26 and Page 6, Line 18) which due to the rotated lat-lon coordinate system corresponds to a resolution of 2.8 km. At this resolution convective-scale circulations are resolved. With decreasing horizontal grid spacing, the convective parameterizations in meteorological models become more and more inappropriate and scientifically questionable given the underlying assumptions. Previous studies demonstrated that a 4-km resolution of the Weather Research and Forecasting (WRF) model with Advanced Research WRF (ARW) dynamics core (Skamarock et al., 2005, 2008), which explicitly resolves convection, gives better results for precipitation forecast compared to the 12-km resolution operational North American Mesoscale model (NAM) model, which employs convective parameterization (Kain et al., 2006; Weisman et al., 2008; Schwartz et al., 2009; Coniglio et al., 2013). Overall, 4-km convection-allowing configurations enable a reasonable evolution of the convective overturning process even though a 4-km grid is too coarse to fully capture convective-scale circulations (Schwartz et al., 2009).

4. Pg1, L10: “emission” should be “emissions”

Reply: Changed.

5. Pg2, l15: Spell out the full name for MARPOL when it first appears in the paper

Reply: Changed.

6. Pg2, l16: “;” should be “,”

Reply: Changed.

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