

Interactive comment on “Contribution of shipping NO_x emissions to the marine nitrogen budget of the western Baltic Sea – A case study” by D. Neumann et al.

D. Neumann et al.

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Response to the comments of Reviewer #1

We thank Fabian Große for the constructive comments on the manuscript. His comments are written in **bold font**. The authors' replies start with a “>” and are written in normal font.

C1

1 General comments

The “Summarizing Discussion” is less of a discussion but more of a summary. Results should be discussed in the context of existing literature (e.g. comparison with the approach of Raudsepp et al. (2013) mentioned in the Introduction; is the tagging approach better/preferable? Why?). It needs to be very clear what the main insights and contributions of the present study are, and how they expand on previous knowledge. In addition, the limitations of the study need to be discussed. For instance, does the year 2012 represent an average year in terms of environmental conditions, inputs from different types of nutrient sources etc. or was it an exception with respect to some factors? If the latter is the case, what implications could that have on the generality of the results. Some limitations of the model are touched in the course of the Results section but those get a bit lost and they are not sufficient for an in-depth discussion. The authors further emphasize the role of the sediment in the Conclusions. So, what influence of the relatively simple sediment parameterization can be expected with respect to the presented results? (Note that this list of potential discussion points is not meant to be exhaustive.) The authors may want to consider separating Results from Discussion more clearly.

As mentioned above, an actual TN budget for overall and ship-borne N (e.g. for the basins defined in Fig. 4) could be a very nice addition to the manuscript. Or even a budget of the overall and shipborne N fluxes between the different model state variables (similar to a model schematic with numbers for the different fluxes for overall and ship-borne N). Since the manuscript is quite concise in its current form, this would not make it overly lengthy. If it's not possible to calculate such budget, i.e. the required fluxes were not stored, the authors should consider changing the title by using “inventory” instead of “budget”.

The Results section is a bit of a laundry list without a clear transitions between

C2

the individual results describing why the specific (upcoming) results are shown. Including such transitions from one subsection/result to the next would help the reader to get what the key focus of each figure is. Also, as a general comment on the results and the discussion: please regularly include crossreferences to figures and figure panels to allow for an easier link between text description and figures. You may want to add panel labels (a, b, c, ...) for easier in-text referencing.

I don't think all additional figures provided in the supplement are necessary, especially since they are only mentioned as existent in the main text. If they don't provide additional relevant information, I'd rather remove them (e.g. time series for the three additional stations listed in the lower part of Table 1). If some of them show very specific features worth discussing, include them in the main manuscript.

Except for the first paragraph, the Conclusions are rather an Outlook with suggestions for future studies. It would be nice to have one or two more actual Conclusion points (which may require additional analysis).

> We split the "Results and Discussions" section into two separate "Results" and "Discussion" sections to better differentiate between results and interpretation. Additional references to the figures were added. We updated the "Conclusions" section. Replies to further aspects mentioned in the previous five paragraphs of the reviewer's comment are part of replies to other reviewer's comments further below.

General note on figures/figure captions: I could only print the manuscript in grey-scale. Many of the described features are barely or not at all visible when printed on grey-scale, i.e. not visible for color-blind people either. Please try some other color scales and also avoid references to color in the text/figure captions. In most cases, the color references can just be removed. Figures that caused me trouble in grey-scale are: Fig 1a,b (basically no spatial differ-

C3

ences visible); Fig. 3 (colors of transects not distinguishable); Fig. 4 (colored regions not at all distinguishable from each other and from land; transect colors not distinguishable; remove color references in caption); Figs. 5 and 6 (just remove color references); Fig. 7a (gradient in darker colors not visible); Figs. 8-10 (color references need to be removed, perhaps different line styles do the trick?); Fig. 11 (gradients in darker colors barely visible: TN looks almost all the same throughout the year; locations of station hard to see).

> Fig. 3: one transect is printed as dashed line, now; the colors are still mentioned in the legend but the descriptions are extended by further information for gray-scaled prints and color blind readers; basin names written in italics so that *land* and *basins* are distinguishable when printed in grayscales; isolines for bathymetry included in the plot;

> Fig. 4: changed colors of the masked regions; added thick black contour to coastline to make land and masks distinguishable; one transect is printed as dashed line, now; the colors are still mentioned in the legend but the descriptions are extended by further information for gray-scaled prints and color blind readers; isolines for bathymetry included in the plot;

> Fig. 5/6: added a proper legend; removed reference to colors from the caption; observations are printed in dark red now (instead of *normal* red);

> Fig. 7a: unit corrected; we see no possibility to improve the color scale because it is already viridis; one cross section is dashed, now;

> Fig. 8-10: kept references to colors but added information on whether the color is lighter/darker than the other one: "*green, lighter color in grayscales*" and "*blue, darker color in grayscales*"

C4

> Fig. 11: refined the color scale; moved symbol indicating the station's location further upwards; further modifications based on further reviewer comments further below

2 Specific comments

Title: I think the speciality of the applied tracing approach is its quantitative nature. Therefore, I'd suggest a slight rephrasing of the title: "*Quantifying the contribution of shipping NOx emissions to the marine nitrogen inventory – A case study for the western Baltic Sea*".

> modified title as suggested; thanks

Line 11: Please state why it is reduced during cyanobacteria blooms.

> We appended to the sentence "...because the cyanobacteria fix molecular nitrogen."

Lines 27/28: Is the difference in deposition velocity really the most important factor for land-sea differences? Isn't the spatial distribution of sources (over land » over water) more important? You also mention it in the next sentence.

> Both aspects are important. There is a clear gradient from the coastline towards the open sea caused by the spatial distribution of emissions sources (higher emissions on land). However, the difference in the deposition velocity has the highest impact (e.g. Fig. 4a in Karl et al., 2019, doi: <https://doi.org/10.5194/acp-19-1721-2019>).

C5

Lines 61-64: I would rephrase this part and get rid of the bullet point with the question, especially since it is only one question. E.g.: "*Here, we combine such model with the nutrient tagging to quantify the contribution of shipping related nitrogen deposition to the total nitrogen (TN) and the different inorganic and organic nitrogen fractions.*"

> removed itemizations; slightly modified the question; kept the question as a question because some readers like to have an explicit research question in the introduction;

Lines 69-72: I would move the part on Raudsepp et al (2013) to the discussion and discuss why one approach is better than the other depending on the research question. The tagging approach is preferable if the current state of a system is to be described as it doesn't change the balance between sources ("*non-disruptive approach*"; see Menesguen and Lacroix (2018), doi: 10.1016/j.scitotenv.2018.04.183). However, if the effect of nutrient reductions should be determined, the actual removal of the considered source is required.

> We did not move the reference to Raudsepp et al. (2013) but extended the discussion on the mentioned topic ("*Why the chosen approach and not simulation without shipping-related nitrogen*".

Lines 72-75: This should go right after the first mention of the tagging method, i.e. after the sentence ending on line 61.

> We prefer the order: problem description, research question, and brief presentation of the methods. Therefore, we removed the sentence "*Using a nutrient source tagging approach (e.g., Ménesguen et al., 2006) . . .*" (lines 59-61), in which the tagging method was mentioned first, and kept the lines 72-75 where they were.

C6

Line 88: In the Discussion, you should include if 2012 is an average or exceptional year in terms of environmental conditions, nutrient inputs from different (types of) sources etc., and how this may affect your results (in case it is somehow exceptional).

> a brief summary of the requested information:

- There were no exceptionally strong Baltic Sea inflows from the North Sea, which might have affected salinity, temperatures and other parameters (Mohrholz, 2018a).
- The *EMEP Status Report 2014* compares the atmospheric conditions of the year 2012 with the conditions of previous twelve years (EMEP, 2014). Although neither the EMEP meteorological forcing (*ECMWF IFS*) nor the same EMEP emission data were used in this study, the descriptions in EMEP (2014) are valid for most aspects of the atmospheric forcing of this study for two reasons: (a) The meteorological forcing of this study (*coastDat2* and *coastDat3*) is a reanalysis for which observational data were assimilated. Therefore, we can expect that the general meteorological features in the *coastDat2/3* datasets are similar to those in the *ECMWF IFS* dataset. (b) The *SMOKE for Europe* emissions used in this study are largely based on the EMEP emissions. The spatio-temporal patterns of the emissions of several air pollutants differ but the annual sums are equal. One exception are the emissions of ammonia, which are calculated bottom-up in *SMOKE for Europe* in some European countries.
- The precipitation amount in Northern Europe in 2012 was above the long term average (EMEP, 2014; p.23).
- The nitrogen wet deposition in Northern Europe in 2012 was above the average of the previous ten years due to increased precipitation (EMEP, 2014; p.49).

C7

- The nitrogen dry deposition in Northern Europe in 2012 was lower than in the previous ten years (high wet and lower was deposition) but the total nitrogen deposition (dry + wet) was still higher (EMEP, 2014; p.49).
- The NO_x emissions in 2012 were lower than in the previous ten year average leading to reduced nitrogen deposition on European average (EMEP, 2014; p.49).
- The increase in nitrogen deposition in Northern Europe in 2012 (due to strong wet deposition) was weakened by the lower NO_x emissions (EMEP, 2014; p.49).
- The ammonia emissions are treated differently in *SMOKE for Europe* than in the EMEP emission model. Therefore, the information on reduced nitrogen deposition in EMEP (2014) is not applicable here. Unfortunately, the Emissions by *SMOKE for Europe* were specifically created for the year 2012 and are not fully comparable to previously by *SMOKE for Europe* create emissions of other years.

> Added this information as subsection to Sect. 2 (*Materials and Methods*)

Figs. 1 and 2: Change their order or adapt in-text cross-referencing. Currently, Fig. 2 is referred to first (line 104).

> changed order

Lines 107-111: Based on the introduction, do I understand correctly that shipping emissions only contribute to NO_x? If so, maybe you could explicitly state that here. It could be worthwhile to provide a number or even a figure panel (in Fig. 1) for how much of the total NO_x deposition is from ships.

> yes, correct, only NO_x; included in the text; good idea; added another row of plots to the figure

C8

Lines 121-124: Should this go into section 2.2 “Marine modelling”?

> Should be in the beginning of 2.1. Moved it there and modified text.

Lines 126-131: I suggest to move this to the discussion and add a statement on if and how this may affect the study results.

> We kept the sentence there but mention and discuss it in the discussion.

Lines 137/138: Is it really “ice cover thickness” and “extent”? Do you mean “ice cover” (as a fraction of the grid cell area) and “ice thickness”?

> forgot a comma; added information in brackets; now: “. . . simulates ice cover (fraction of grid cell area), thickness and extent”

Lines 140-156: This needs a little bit of reordering. The sentence on the river loads should go to the end of the paragraph and the first sentence should be merged with the one on ERGOM’s development at the IOW.

> reordered and merged as suggested

Lines 146/147: Has ERGOM atmospheric P deposition included? I am not sure after reading “phosphate” and “atmospheric deposition” in the same sentence. Please clarify.

> yes, P deposition is included (as phosphate); Replaced “or” by “and” at two locations and added “ammonium” to reduce ambiguity; now: “Inorganic nutrients – i.e. nitrate
C9

(NO_3^- , ammonium (NH_4^+), and phosphate (PO_4^{3-}) – enter the system via river input, atmospheric deposition, and remineralization of organic matter.”

Lines 160-162 (and thereafter throughout the manuscript): I suggest to simply distinguish between N (without “all”) and ship-borne N (“N_{ship}”). For ratios, I would then simply write “TN_{ship}/TN” etc. It makes it more legible and text descriptions less cumbersome. Further suggest to rephrase this sentence to: “. . . another variable containing only shipping-related nitrogen (subscript “ship”). Process rates for the latter ones are equal to the process rates for the original state variables scaled by the relative contribution of shipping N to the educts.” Please also add on what frequency model output has been stored.

> We removed *all* at some locations. However, in our opinion the usage of *all* prevents ambiguity in some situations for some readers. Therefore, we prefer to keep it at most occasions.

> State variables in full spatial resolution were written out as monthly means. We had a daily output interval only at the locations of measurement stations. We added this information as an extra paragraph to the Materials and Methods Section on the marine model (currently Sect. 2.2).

Lines 190-195: I suggest removing the part on oxygen. It is no relevant for the study, and it seems to me that persistent hypoxia/anoxia in the deep basins of the Baltic Sea is mixed up with seasonal hypoxia in parts of the coastal zone.

> removed

Fig. 4: Could be merged with Fig. 3 or at least put as Fig. 3b (ideally with the map inset shown in Fig. 3a/now Fig. 3). There is a horizontal line a few pixels

above the horizontal border between “*Belt Sea*” and “*Arkona Basin*”, which has the same color as the “*Oresund*”. Please double-check that there is no error with the region mask in your analyses.

> We would prefer to keep the figures separated so that they are closer to the relevant text passages. The figures are planned as one-column figures in the final document. Hence, they will consume less space in the final document compared to the discussion version. Thanks for looking in details into the plot and identifying the horizontal line. The plotting program bilinearly interpolated between the masks. We manually draw colored boxes atop of the interpolated regions, which we did not do properly. The issue is fixed now. It only affected this figure and no data.

Lines 208/209: Please state why you picked the three stations that are shown. Do they represent specific regimes? E.g. coastal vs. offshore? Re-evaluate whether you really need the three stations shown in the supplement. If you want to make the validation more sound, then you should point out somewhere in the validation section that model-data agreement is good also at the other stations presented in the supplement. Remove the sentence on the stations that were ignored.

> add text after first sentence: “*They represent different regimes in the considered region: two offshore stations in different basins (OMBMPM2 and BY2) and one station close to the shore (DMU547). Additionally, sufficient measurement data were available at these locations.*”. Replaced the second sentence by “*Validation plots at three additional stations are presented in the supplement and show a similar outcome. They are included to indicate that not just the three best stations are shown here.*”.

Line 213: Could you specify what bathymetry criteria are used. Perhaps you can add relevant isobaths to Fig. 4?

C11

> added isolines for bathymetry to Fig. 4; the rough spatial extend of the domains/masks was taken from the referenced publication and then fine-tuned based on the used bathymetry

Line 219 and Figs. 5 and 6: I would suggest switching the order of the T and S columns as you first talk about T and then S.

> order of columns switched as suggested

Lines 222/223: The vertical mixing might be a point for the discussion.

> Included in paragraph *Discussion* (first paragraph).

Lines 225-227: These two sentences contradict each other. First “*all is good*”, then nitrate is not.

> The one sentence (“*all is good*”) means the sea surface and the other sentences means the sea floor. Add “*... at the sea floor*” to the first sentence to clarify this.

Lines 239-248: Should this go into the discussion?

> moved to the discussion

Lines 244-246: I don't understand this part. Please clarify what is supposed to happen but does not in the model, and how this affects the deposition.

> extended this passage and added reaction equations (now in the Sect. *Summarizing discussion*)

C12

Fig. 8, caption: The last sentence explains how percentiles (10%, 50%, 90%) were calculated for the ratios. However, following this approach, all ratios get the same weight, which may change the results especially during periods of strong short-term changes (e.g. during the spring bloom). I would suggest calculating daily (assuming daily model output), spatial integrals of mass (i.e. concentration times volume) of TN and TN_{ship}. You can then calculate TN_{ship}/TN ratios and use the TN mass as weights to calculate weighted percentiles. This way you ensure that short-term changes in concentrations and volume (ERGOM uses a free surface, right?) are accounted for correctly. Analogously, you can calculate the weighted percentiles for TN by dividing the daily time series of regions' TN mass by the daily time series of the region' volumes, which gives the spatially weighted-average TN concentration, and using the daily time series of the regions' volumes as weights. Analogously for the other variables.

> For the basin means, we had only monthly mean values available as basis for the calculations. Temporally higher resolved data were only written out at the locations of measurement stations. This was done to save disc space. The plotted variability rather is a spatial variability than as temporal one. We added this information to the figure's caption.

Fig. 10: What is the cause for the strong peaks in the 90% percentiles of PON (and TN) in fall and winter at DMU547?

> The detritus concentrations are very high at three days in September and December. The high concentrations correlate with peaks in the U and V current velocities at the sea floor. Probably, detritus was resuspended from the sea floor. Values of relevant state variables at different depths at this station are, now, provided in the supplement (dmu547_peak_autumn.pdf);

C13

Line 292: 6% is not “very high”

> replaced by “... ratio peaks with $\approx 6\%$...”

Line 297: An introductory sentence why you show the vertically resolved plots would be nice.

> added two introductory sentences

Lines 303-313: I would suggest rewriting this text part as a “normal” paragraph. The bullets make it appear like a list of very important information but they are mostly a detailed description of the dynamics of DIN, DON and PON. If you prefer keeping it as a bullets, please correct the numbering (“3” occurs twice).

> itemization converted into one paragraph

Fig. 11: Would it make sense to add a row for PON since it's referred to a lot on lines 303-313? Perhaps you could label the two transects in Figs. 3/4 (e.g. T1/T2 or S1/S2) and use the label in the figure caption. I was a bit confused about the term “profiles”: do you have profile data available? If so, why didn't you use them for validation?

> added T1/T2 to Figs. 3 and 4; added PON to Fig. 11; We have profile data available and we used them to calculate the 10 m-averages in the validation section. However, it was not mentioned explicitly in the *Materials & Methods* section. We added a sentence “Vertical profiles were measured at most stations.” to the MM Section.

C14

Lines 329-332: Please explain the cause of the difference between Oresund and Arkona Basin. Section 3.5: Include references to figures, it's hard to remember what result derives from which figure. Discussion should be in the same order as the results, i.e. annual cycle (lines 329-332) should be discussed before the vertical. And as mentioned in my general comments, please provide an actual discussion.

> added explanation (in the Discussion)

> references to the figures added

> moved paragraph on vertical distribution further downward

3 Technical corrections

Line 8: “*the atmospheric input*”

> included

Line 9: “*in shallow coastal regions*”

> replaced

Line 19: Include reference to MSFD (EU, 2008) for the GES

> included

C15

Line 24: remove “*approximately*”

> removed

Line 25: “*atmospheric nitrogen deposition*”

> added

Line 32: “*region where high amounts*”

> modified

Line 43: move HELCOM reference to end of sentence

> moved

Line 45: “*That means*”

> modified

Line 46: “*ships built after 2021*”

> modified

Lines 56/57: “*in the system and their deposition sites*”

C16

> modified; but used “*the location of their deposition sites*” instead of “*their deposition sites*”

Line 60: “*key variables in biogeochemical models*”

> modified

Lines 63/64: You also provide analyses for organic N, not just TN and DIN

> Thanks. We will include it.

Lines 67/68: remove the sentence “*We used an ...*”

> removed

Line 68: “*Within ERGOM, the tagging*” instead of “*Previously, this tagging*”

> modified

Line 71: “*and another one without*”

> modified

Line 79: “*were not coupled on-line.*”

> modified

C17

Line 98: “*deposited*”; use full name of SMOKE

> modified; included

Line 99: use full name of STEAM

> included

Line 100: use full term for IMO

> included

Caption of Fig. 1: remove long name of CMAQ and the note

> removed

Line 109: Please add in parentheses what HONO is

> HONO is no abbreviation of a substance name like PAN and PNA but the chemical formula. We reordered the list to have the two abbreviations in the end.

Line 138: remove “*past*”

> removed

Line 146: “*Inorganic*” instead of “*Basic*”?

C18

> replaced

Line 155/156: remove the name of the supplement; it can all be found in the readme.

> removed

Line 157: “*by the method*”

> modified

Line 158: “*and used*”

> modified

Line 173: “*in the eastern*”

> modified

Lines 178-180: change order of the two sentences

> changed order

Line 181: “*emergence of stratification*”

> modified

C19

Line 183: remove “*read*”

> removed

Line 185: “*N:P*” => N and P have not been introduced

> added “*nitrogen-to-phosphorus*”

Lines 189/190: “*algal bloom period ends in autumn when stratification*”

> modified

Line 193/194: remove “- *denoted as oxygen minimum zones* -”

> removed

Lines 205/206: “*were aggregated into a monthly ‘climatology’*” (‘climatology’ with apostrophes as seven years do not really warrant a proper climatology)

> added

Table 1, caption: remove “*and model evaluation*”; remove color references to figures

> removed; reformulated caption slightly

Table 1 should come before Fig. 4 as it is referred to first.

C20

> Table 1 is before Fig. 4 in the LaTeX document. We will take care that they will be properly ordered in the final version.

Fig. 5: remove “*var [unit] (see header)*” on the left; Why are some individual ticks on the y axes not labelled (e.g. 0 in bottom left panel or 15 in the one next to it)? Use “*mmol N m-3*” and “*mmol P m-3*” as units for NO₃ and PO₄, respectively; caption: remove color references; “*Each column presents one state variable*”; “*Vertical lines and shaded areas show the monthly*”; remove everything after the first “*Supplement*”

> removed “*var [unit] (see header)*”; Default plotting in R – better this way (adjusted minimum of y-axis; decreased font size of two plots; manually added some values along the y-axis)? Otherwise the labels would have a too small font size; We would like to keep the units SI conformal but ‘N’ and ‘P’ are not defined by SI. As long as we have amount (‘moles’) and not mass (‘g’), x mol of N are equal to x mol of nitrate; colored references removed; column/row corrected; “*the*” in the sentence on “*vertical lines and shaded areas*” removed; removed text after “*Supplement*”;

Line 212: “*Basin definitions by Omstedt*”

> modified

Line 215: “*the model’s open boundary*”

> modified

Line 219: “*Sea surface temperature [...] but sea surface salinity*”

C21

> removed “*the*”

Fig. 6: remove “*var [unit] (see header)*” on the left; Why are some individual ticks on the y axes not labelled (e.g. 15 in bottom left panel)? Use “*mmol N m-3*” and “*mmol P m-3*” as units for NO₃ and PO₄, respectively; Why are the depth ranges at the first 2 stations not equivalent to 10m as stated on line 198? Caption: “*Same as Fig. 5 but for the bottom 10 m.*”

> adapted like in Fig.5; In shallow regions below ≈ 30 m less than 10 m (above the bottom) were considered. Statement in l. 198 was correct; first sentence simplified similar as suggested

Line 222: Here and throughout the manuscript, do you mean “*seasonal*” with “*intra-annual*”? Since you show monthly data, any shorter-term variability is averaged out.

> Yes, we meant “*seasonal*”. We replaced “*intra-annual*” by “*seasonal*”.

Lines 227/228: replace “*The modeled water column is stronger stratified than the real water column*” with “*Simulated salinity suggests that stratification is overestimated by the model*”

> replaced

Fig. 7: Should the unit be “*mmol m-3*”, not “ *μ mol m-3*”? Remove the “*all*” subscript; stations/transects hard to see in grey-scale; caption: remove color references; “*White areas are on land in the MOM-ERGOM domain.*”

C22

> Yes, should be “*mmol m⁻³*”; We think that it is a good idea to add a subscript to all TN to be unambiguous; removed color references;

Lines 239-241: “*origin and caused by a lower horizontal grid resolution of the CMAQ compared to MOM-ERGOM and interpolation over the land-sea interface.*”;
remove the last sentence

> modified

Line 247: remove “*to the ground/sea*”

> removed

Line 249: here and later: “*The contribution of shipping-related nitrogen to TN (TN_{ship}/TN) . . .*”

> resolved here but not at later locations

Fig. 8: I would suggest removing the absolute shipping TN, DIN, etc. since it is pretty much zero compared to the overall quantities and hardly visible especially in grey-scale. The y axes labels could then be “*overall*” for the even rows and “*shipping*”; I suggest putting TN in the first column as you previously analyzed TN, so now you increase the level of detail from TN to its inorganic and organic compartments; add to the caption that it’s 2012 only and remove “*in 2012*” from the x axes labels; caption: “*thick*” instead of “*think*”; remove “*in the odd rows*”; “*For the ratios, . . .*”; remove color references

C23

> We would like to keep the green lines in odd rows because they make hugh difference between untagged nitrogen and shipping-related nitrogen clear and do not disturb the understanding of the plots.

> order of DIN, DON, PON, and TN: DIN is described first and TN last in Sect. 3.3. Hence, it is reasonable to keep the order as it is. For the same reason, the *temperature* and *salinity* were switched in Figs. 5 and 6.

> replaced “*think*” by “*thick*”

> kept color reference but added description in terms of darker/lighter color

Line 255: remove “*with all nitrogen*” and “*all*” subscript

> removed “*with all nitrogen*” but kept the subscript to prevent ambiguity

Lines 259/260: “*which are the sum of DIN, DON and PON*”

> modified

Line 261: “*In contrast, the DIN concentrations are elevated ($\approx 5 \text{ mmol N m}^{-3}$) throughout the year in the Oresund .*”

> modified

Lines 262/263: “*by riverine nutrient loads*”; remove the names of the rivers listed in parentheses

C24

> removed

Lines 264/265: “The relative contributions of shipping N to DIN, DON and PON are very small.”

> modified

Lines 267/268: “from 1.5-2% in January to about 1% in July”

> modified

Fig. 9: These are no daily values (see caption); put only one station/depth label per station (like in Fig. 8: change caption to: “Same as Fig. 8 but for specific stations (see Fig. 1).”

> The sentence was formulated ambiguously. We have daily mean values and calculate monthly percentiles from them. In Fig. 8, we had only monthly mean values. Background: We saved model output at specific locations (measurement stations) in daily resolution. But, the full spatial model output was only stored in monthly resolution to space disc space. Fig. 9 shows the variability in time, whereas Fig.8 shows variability in space.

Line 274: “However” instead of “But”

> modified

Line 275: remove “as presented in Sect. 3.2”; “in the open ocean”

C25

> removed and modified

Line 278: These are no means and no daily data

> adapted to be less ambiguous; see reply to comment on Fig. 9;

Fig. 10: put only one station/depth label per station (like in Fig. 8); again why is the depth range not equal to 10 m for the first two stations? Change caption to: “Same as Fig. 9 but for the bottom 10 m.”

> station label: updated; depth range: see reply to comment on Fig. 6; modified caption similar as suggested;

Line 286: remove “data”

> removed

Line 291: “at the surface due to vertical stratification.”

> modified

Line 297: State what quantities are shown.

> added; also included information on temporal resolution

Line 299: “causing the low values in the south.”

C26

> modified

Line 300: “*later*” instead of “*delayed*”

> modified

Line 303: remove “*reaches* \approx 12.5 %”

> removed

Fig. 11: add “*latitude (N)*” to x axis on left and right; station lines are barely visible in grey scale, same for the temporal development; caption: remove “*is plotted*”, remove last sentence

> added ‘latitude (N)’; changed color of station-symbol and -line; improvement of color-scale does not seem to be possible when it should remain equal for all 24 plots; removed both;

Line 315: Please rewrite the sentence such that models and data are only mentioned once

> rewritten

Line 317: “*The concentration of shipping-related TN ...*”

> modified

C27

Line 320: “*... the contribution of shipping-related N to DIN was highest ...*”

> modified

Line 334: “*to TN*”

> modified

Line 335: “*the NOx emissions*”

> modified

Line 337: “*to DIN*”

> modified

Line 349: “*.*” after “*)*”

> added

Line 368: add first name of co-author (although I would suggest to only use initials in the whole author contribution section)

> changed to: only initials

Line 383: “*program whose intense*”

C28

> modified

Interactive comment on Ocean Sci. Discuss., <https://doi.org/10.5194/os-2019-78>, 2019.