

Authors response to Report #1 – Fabian Lennartz (R1)

We are very grateful to Fabian Lennartz for his positive review of the manuscript. Below his remarks, comments and question are addressed in detail. We are in particular grateful for questions addressing the uncertainty of the method, which led to changes in the manuscript and helped to improve the manuscript.

R1.0. “Congratulations for your work. It was an interesting reading and I believe that the generic approach you proposed to account for dynamic population will be used again in future exposure studies. The thorough description of the methodology is helpful to understand the results and support the conclusions. [...] The overall presentation is well structured, the language seems fluent and precise for the non-native speaker who I am and the quality of the figures is good.”

Response to R1.0:

We thank the reviewer for his assessment of the scope, methodology and structure of the manuscript.

R1.1. “The content of the paper is somewhat richer than the title suggests, I would recommend to modify the title or the text accordingly. For example, if one focuses only on NO_x emissions are the second part of Section 2.5 (pg 10 l.25 to pg 11 l.3) and the last part of Section 3.2 (pg 18 l.23 to relevant?”

Response to R1.1:

We aware of the extent of the paper and decided to move some parts to the annex, to focus on the scope suggested by the title and the reviewers suggestions:

- We narrowed down the chapter on evaluation of concentrations in the manuscript and moved the detailed evaluation into the Annex. This includes the part about influence of shipping by PM_{2.5} (pg 18 l.23).
- When it comes to the second part of section 2.5 (pg 10 l.25 to pg 11 l.3), which deals with uncertainties in the NMVOC emission inventory for shipping, we decided to move this section to the discussion part of the manuscript, to discuss uncertainties and improvement possibilities. This is necessary due the chemistry of ozone, NO_x and volatile organic compounds (VOC), which represents one of the major uncertainties in the field of atmospheric chemistry, especially in urban areas (Sillman, 1999). The discussion of uncertainties due to NMVOC emissions and chemistry was also requested by Reviewer 2 (R2.3) and tackles the R1.3.

- Besides these reductions of the manuscript's extent, we believe that the amount of given information is necessary to follow:

- a. the preparation of emissions and concentrations as well as their evaluation with common methods,
- b. the development of the generic approach for population activity exposure assessments and
- c. the discussion of uncertainties in population exposure, which is connected with modelled concentrations and population activity (as requested in more detail by Reviewer 1 and 2).

R1.2. "Furthermore, I feel like one studies an exposure to concentrations rather than to emissions, but I know that such expression can be found in the literature."

Response to R1.2:

Indeed, we study the exposure to concentrations, which are a result from shipping emissions. Nevertheless, we decided not to change the title, due to the common use of this terminology in literature, and the close relationship of emissions and concentrations, especially on the urban scale. Nevertheless, we clarified the study scope by changing the first sentence of objectives in the introduction to: "The objective of this study is to identify the impact of emissions due to local shipping activities on air quality and population exposure to concentrations of NO_x in three major Baltic Sea harbour cities: Rostock (Germany), Riga (Latvia) and the urban agglomeration of Gdansk-Gdynia (Poland)."

R1.3. "Here below you will find two questions about your work: If you wanted to reduce uncertainty on the presented results, how would you prioritize the following tasks improvement of emission inventories, improvement of model performance (better fit with observed values, higher spatial resolution, etc.), use of more precise/diverse activity patterns, use of more precise/diverse infiltration factors, etc.?"

Response to R1.3:

In the following, we will discuss the review comments R1.3, R2.3 and R2.4 by reviewers 1 and 2 jointly, due to the similar nature of the comments. The comments deal with questions of uncertainty in the developed generic approach. We decided to dedicate a paragraph to this issue, integrated additional information and parts of the existing manuscript to restructure the discussions chapter 4 as follows to replace the existing chapter 4 in the reviewed manuscript:

Short answer in the order of priority:

1. a better representation of emission inventories in CTM,
2. city- and microenvironment-specific infiltration factors for indoor environments,
- 5 3. city- and microenvironment-specific time profiles of population activity, and
4. city-specific spatial distribution of population in representative microenvironments.

Long answer as it will be used for the revised discussion section of the manuscript:

4 Discussion of the generic exposure approach

10 We developed a generic approach to model population activity for exposure calculations (Sect. 2.6.2) to bridge the gap between static residency population numbers and very dynamic but specific population activity data derived from surveys or gathered with mobile devices, which were both not available in the harbour cities of this study. Thus, we used generic data and a set of assumptions, which introduces spatial and temporal uncertainties in the exposure calculation, additional to those of the applied CTM system. Exposure is the cross-product concentrations and population density. Therefore, all uncertainties that play a role for either of them have to be considered.

20 In terms of uncertainties within the applied CTM system to produce concentrations, the range of uncertainty can be identified by comparisons with measurements. The evaluation of measurements (Supplement SII, Table SII-2) shows a range of -26% to +4% for BIAS in annual measured vs. modelled NO₂ concentrations at different stations in Gdansk-Gdynia. In Rostock, there are higher underestimations of -56% to -32%, while in Riga the range is -60% to -4%. High underestimations in all cities mainly occur at or near traffic stations. Matthias et al. (2018) and Bieser et al. (2020) have shown, that the biggest uncertainty in CTM simulations are mostly due to emission data, which are a key driver and a major source of uncertainty to atmospheric chemistry transport models. Especially in urban areas, e.g. concentrations of NO_x depend linearly on the local emissions. In emission modelling the amount, temporal and spatial distribution of emissions are often uncertain and thus have a high sensitivity. For example, NMVOC emissions for ships in port areas were not available as output from STEAM. This restriction led us to estimate NMVOC emissions based on the Carbon Monoxide (CO) emissions provided. Products of incomplete combustion, like CO and NMVOC, are difficult to estimate, because these emissions are very sensitive to engine load changes, engine control (mechanics/electronics), service history

and fuel injection. Very little experimental information is available concerning NMVOC emissions from modern marine engines at sufficient level of detail and NMVOC emission factors based on measurements done decades ago may not represent NMVOC emissions from modern marine diesel engines accurately. Lack of detailed measurement data is probably because emission measurement standards (ISO 8178) do not require NMVOC classification, but report NMVOCs as total hydrocarbons instead, which makes evaluation of NMVOC species very difficult, hindering the CTM description of secondary aerosol formation at consecutive modelling effort. Nevertheless, in this study we used a CO emission to NMVOC emission ratio of 1.4, which is representative for emissions from auxiliary and main engines at an engine load of 70–80% (Aulinger et al., 2016), to calculate NMVOC emissions from STEAM CO emissions in Rostock, Riga and Gdansk-Gdynia. These uncertainties in emissions will translate to uncertainties in NO_x concentrations due to the chemistry of ozone, NO_x and volatile organic compounds (VOC), which represent one of the major uncertainties in the field of atmospheric chemistry, especially in urban areas (Sillman, 1999). Another example for uncertainties due to emissions are traffic emissions, which play a major role in the overall urban emissions. The exposures in the ME_traffic are very likely to be under-predicted in Rostock and probably also in Gdansk-Gdynia and Riga, due to the following reasons. In Rostock, the traffic emission modelling is not based on actual traffic density data but only was spatially disaggregated based on road type classification and corresponding factors, which represent a national average. While in Riga and Gdansk-Gdynia the traffic emissions are based on traffic counts, they also do not account for all the effects of traffic congestion, slowing down of traffic in certain locations and streets and the effects of idling, and the deceleration and acceleration of vehicles. Traffic congestions can increase emissions in streets during rush hours (Gately et al., 2017; Requia et al., 2018; Smit et al., 2008). The evaluation at traffic stations has also shown that NO_2 was modelled with a high negative BIAS although EPISODE-CityChem was run with activated Street-Canyon-Module and therefore included treatment for dispersion in street canyons. The ME_port shows in all urban domains lower exposure to NO_2 compared to ME_work. This is mainly due to the detailed allocation of people directly employed by the port to the ME_port, which are distributed to the comparably large port areas.

Besides emissions, also meteorological fields and regional boundary conditions are crucial inputs for correct CTM simulations. Nevertheless, Karl et al. (2019a) have proven good agreement with measurements for the regional boundary conditions as calculated with CMAQ, and the performance of the meteorological module of TAPM shows very good agreements with measurements. Therefore having correct emissions is the highest priority in terms of improving the concentrations of NO_2 , which then will linearly improve the results of exposure calculations.

In terms of uncertainties within the population activity, which is the second part of the cross product to calculate population exposure, there are four major factors in the developed dynamic population activity approach that needs to be considered: the number of population, the temporal distribution of population, the spatial distribution of population and the application of infiltration factors for different microenvironments. In the following, these will be discussed in detail.

In this study, the population in each urban domain was derived from a population density map, valid for the European Union, instead of national or municipal population counts. This introduces biases in terms of total population numbers and the spatial distribution of people in their home environments. We have shown that the total population number derived from population density maps in this study is altered by 9%, 12% and 8% for Rostock, Riga and Gdansk-Gdynia respectively compared to population counts valid for the cities of interest (Table 3). Nevertheless, the advantage of this approach is the detachment from municipal boundaries or statistical zones, which are often used in population counts; these could lead to blind spots in research domains, which exceed municipal boundaries or statistical zones. A future development will be the integration of 'Population estimates by Urban Atlas polygon', which is a Copernicus Land Monitoring Service product in preparation (<https://land.copernicus.eu/local/urban-atlas/population-estimates-by-urban-atlas-polygon>, 06.02.2019). Besides this, we are uniformly distributing the derived total population with UA2012 land use classifications to spatially disaggregate the total population. A future development of this approach will be the integration of population density maps as a proxy in the distribution of population to the home environment, to integrate a weighted distribution of population to the UA2012 land use classifications. This will also lead to a clearer distinction of areas, which are allocated to work and home environments at the same time.

We considered the UA2012 land use classification "Continuous Urban Fabric" as both home and work environment with 30% and 70% share, due to the description of the UA2012 classification, which includes central business districts. To check the impact of this assumption, we changed the applied split of 30% ME_home and 70% ME_work, in two tests to (1) 50% ME_home and 50% ME_work and to (2) 70% ME_home and 30% ME_work in the Gdansk-Gdynia domain. By changing the distribution of ME_home to 50%, the contribution of ME_home to the total annual gridded mean increases by 0.7%, while the total annual exposure increases by 1.8%. Changing the distribution of ME_home to 70%, increases the contribution of ME_home to the total annual gridded mean by 1.2%, while the total annual exposure increases by 3.2%. In the same tests, the ME_work is changed to 50% and 30%, which results in a decrease of the ME_work contribution to the annual grid mean by 0.3% and 0.5%. Therefore, we evaluate the uncertainty of the applied split of 70% ME_work and 30% ME_home in the UA2012 land use class

“Continuous Urban Fabric” to have limited influence on the overall exposure results. Nevertheless, due to a lack of information about specific population activity in any of the urban domains, we cannot validate our assumptions in distributing population to the MEs and the connected UA2012 land use classifications. Based on the descriptions of the UA2012 land use classifications we matched the best fitting microenvironments but still introduce uncertainties, e.g. in the category “Industrial, commercial, public, military and private units” which contains not only work environments but also non-work environments, e.g. schools, universities, museums or churches. When it comes to ME_work, we also considered the UA2012 class “Continuous urban fabric” to mainly constitute indoor work environments in city centres and the UA2012 classes “Industrial, commercial, public, military and private units”, “Mineral extraction and dump sites” and “Construction Sites” to account for mixed indoor and outdoor work environments. In future studies, a clearer distinction of the UA2012 categories in terms of numbers of workers and indoor/outdoor classification should be done; e.g. the number of workers in the category “Mineral extraction and dump sites” could be taken from city-specific statistics and the category could be classified as outdoor only environment. Besides this, we considered the amount of commuters, taken from municipal statistics, in the ME_work and ME_traffic and thus accounted for people, which are additionally exposed to pollution in traffic and work environments. The consideration of commuters in Gdansk-Gdynia leads to a 4% higher total annual population exposure and a 20% higher annual exposure in ME_work. For a better distribution of the ME_work and ME_other we plan to use the “point of interest” feature in OSM data as proxy in future studies, which potentially allows for a better distribution between work and other activities and to identify very busy city-centres.

Besides uncertainties in the spatial distribution, we also introduced uncertainties regarding the temporal distribution, which is based on a temporal profile for the city of Helsinki (Soares et al., 2014). We adapted this profile and then added features, which we found to appear in other European cities, such as traffic rush hours in the morning and evening. However, such a generic profile is not able to reflect the actual population activity throughout the day. Moreover, there are regional and national differences, e.g. the siesta in Mediterranean countries. Still this pattern emulates a dynamic population, which moves between environments and is exposed to different levels of pollution throughout the day. In comparison to traditional approaches, which assume people to be at their residence (home address) all the time, we believe this approach is beneficial in particular for cities in European regions where data from surveys or positioning data from mobile devices is missing. We compared population exposure to NO₂ based on our dynamic population activity approach, with population exposure based on a static approach to analyse the effect of a population moving in space and time on calculated population exposures. In this test, we allocated the total population all day (100% of the time) to the home environment (ME_home)

in order to simulate a static approach. The dynamic activity considers people ‘moving’ diurnally between different MEs. Moreover, we ran simulations with and without infiltration factors to test the effect of outdoor concentrations infiltrating to indoor environments in the static and dynamic approach. The comparison between the static and the dynamic approach without the consideration of IF (i.e. indoor air concentrations are the same as in the surrounding outdoor air) shows a decrease in total annual exposure in each city (Table 6). Therefore, the consideration of diurnal dynamic activity in different MEs leads to an increase in total population exposure. This is an effect of people moving to areas which are more polluted and additionally the effect of commuting inside/outside of the city.

Another assumption made in calculating exposure in different environments is the infiltration of outdoor pollutant concentrations into indoor environments. We have considered the influence of outdoor air pollution on the total population exposure. However, we have not addressed indoor sources and sinks of pollution although, indoor sources such as, e.g. tobacco smoking, cooking, heating and cleaning might cause additional short-term concentration maxima in indoor environments. We have also assumed that infiltration is temporally constant, changing only with the seasons. Nevertheless, we took into account the infiltration of outdoor pollution into indoor environments (ME_work and ME_home) using IFs. To check the impact of IFs for the indoor environments, we increased and lowered the applied IFs in ME_work and ME_home in the city of Gdansk. An increase of the IFs by 0.1 in both MEs leads to a linear increase of 10% in ME_home and ME_work respectively. The total exposure increases by 10%. When it comes to the relative contribution of each ME to the total exposure, the relevance of ME_home increases to 57% (+2.5% points) and ME_work to 14% (+0.4% points). A likewise decrease of IFs by 0.1 shows the same changes with opposite sign. Thus, the impact of the adapted IFs on exposure in environments that are mostly indoor environments has a significant influence on the total exposure results with a linear response of the total exposure to changes of the IF. The MEs ME_other, ME_traffic and ME_port are considered to be outdoor environments. When it comes to the ME_other, which is an outdoor-only environment in this study, the exposure is heavily dependent on the season, due to more people spending their time outdoors in summer than in winter. This has not been considered in this study but should be taken into account in future studies. Nevertheless, the ME_other areas in the city-centre are mainly green urban areas and therefore in summer potentially areas of high exposure. In general, the applied IFs for NO_x as derived from Borrego et al. (2009) are representing an average of infiltration measurements in Korea (Baek et al., 1997), Hongkong (Chau et al., 2002) and the United Kingdom (Dimitroulopoulou et al., 2006). Thus, in future studies it is desirable to derive and use IF, which are representative for the city-specific building infrastructure to account for different air-intake techniques, building structures or different ventilation manners. Better parametrization to derive

more representative IF could be derived from a combination of the EU Buildings Database, the UA2012 and climate data.

Taking into account all uncertainties and possibilities for improvement, we promote this approach for European regions, in which actual data on population activity is not available, with the overall goal to improve existing exposure calculations for policy support. Nevertheless, the highest uncertainties and therefore possibilities to improve the results of the exposure calculations are

1. a better representation of emission inventories in CTM,
2. city- and microenvironment-specific infiltration factors for indoor environments,
3. city- and microenvironment-specific time profiles of population activity, and
4. city-specific spatial distribution of population in representative microenvironments.

Table 1: Comparison of total exposure to NO₂ in each city for simulations with static and dynamic population, with and without ME- and seasonal specific IF. The approach used in this study (Dynamic activity with IF) is representing the baseline (100%).

Scenario	Rostock		Riga		Gdansk-Gdynia	
	Total NO ₂ exposure [µg m ⁻³ * pop]	Rel. change to baseline	Total NO ₂ exposure [µg m ⁻³ * pop]	Rel. change to baseline	Total NO ₂ exposure [µg m ⁻³ * pop]	Rel. change to baseline
Dynamic Activity with IF	9.15 E+09	(baseline)	6.55 E+10	(baseline)	7.66 E+10	(baseline)
Dynamic Activity without IF	1.25 E+10	+ 27%	8.88 E+10	+ 26%	9.85 E+10	+22%
Static Activity with IF	8.89 E+09	- 3%	6.02 E+10	- 9%	6.88 E+10	-11%
Static Activity without IF	1.19 E+10	+ 23%	8.03 E+10	+ 18%	9.18 E+10	+17%

R1.4. “Have you tested the impact on exposure of a different emission sector such as traffic?”

Response to R1.4:

Not yet, but further studies with improvements of microenvironments and focus to different sectors, especially traffic, are planned. A study on the integration of better and region-specific infiltration factors in the traffic environment is in progress. Thus, we integrated the following sentences in the outlook section of the paper:

“When it comes to the traffic environment, we also aim at integrating region-specific measurements of outdoor to indoor concentration ratios. Besides these efforts, further studies to test the impact of different emission sectors, such as traffic or industry, in different microenvironments are planned.”

List of Minor changes requested by R1 have been considered in the final manuscript:

“pg 1 l.15 exposure TO outdoor (...)”

- **changed to “exposure to outdoor [...]”**

5 “pg 7 l.26 grid resolution of 4 km or 2 km but not 4 km²”

- **changed to “4 x 4 km”**

“pg 10 l.21 I think the first reference should be Hulskotte and Denier van der Gon, 2010”

- **changed to “Hulskotte and Denier van der Gon, 2010”**

“pg 10 l.28 mechanics/electronics instead of mechanic/electronic”

10 ○ **changed to “mechanics/electronics”**

“pg 10 l.30 modeling is here used with one l instead of two”

- **changed to “modeling”**

“pg 16 l.1 I’d stop the sentence after “the observed values” (+ FAC2)”

- **the sentence now stops as suggested by R1**

15 “pg 27 l.16 I wouldn’t include a reference in the conclusions”

- **we excluded all references from the conclusions, which are unnecessary repetitions of previous mentioned references**

“pg 27 l.20 to 22 I wouldn’t keep the part about PM10 and PM2.5”

20 ○ **We deleted the part about PM10 and PM2.5 due to the scope of the paper, which is NOx. Therefore results on PM10 and PM2.5 are excluded from the conclusions.**

“pg 27 l.29 a four-step approach is mentioned in the conclusions while a five-step one is mentioned in Section 2.6.2”

- **We changed the respective parts to “a four-step approach”**

25 - “pg 29 l.11 the code for exposure modelling should be made available before publication or this sentence should be deleted.”

While the code is still in preparation for publication, we deleted the sentence about code availability.

Author's response to Report # 2 – anonymous referee (R2)

We are very grateful to the anonymous reviewer of the manuscript. Below her/his remarks, comments and question are addressed. We are in particular grateful for questions addressing the uncertainty of the method, which led to changes in the manuscript and helped to improve the manuscript.

R2.0. *“This study was an example investigating the urban population exposure to local shipping emissions. To raise a generic approach, the authors started from the very beginning including the built up of emission inventory and spatial-temporal allocations for high resolution modeling. To obtain the health impacts, exposure responses were also studied. As shown in the title, NO_x is the main target although other pollutants were also discussed. The study is comprehensive and flawless from the structure to presentation. Overall, this manuscript is well organized. This topic is relevant to the scope of ACP and also in time addressing the pollutant from local shipping emissions. Thus I recommend publication of this paper within ACP.”*

Response to R2.0:

We thank the reviewer for her/his assessment of the scope, methodology and structure of the manuscript.

R2.1. *“As mentioned by the other reviewer, this manuscript is a little bit longer than the regular ones. Shall the authors consider to put some materials in the supplemental materials or refer to some other previous studies? For example, the built up of emission inventory or the spatial-temporal allocation?”*

Response to R2.1:

- Please see response R1.1 to reviewer 1 for a similar request.
- We decided to keep the built-up of emissions inventory incl. the spatial-temporal allocation because they are a key driver and a major source of uncertainty to atmospheric chemistry transport models (Bieser et al., 2020, Matthias et al., 2018).

R2.2. *“If possible, comparisons with similar EI studies would be very helpful.”*

Response to R2.2:

Enquiries beforehand this study resulted in only few existing studies on population exposure to NO_x in urban areas. Most studies focus on PM₁₀ or PM_{2.5} (e.g. Soares et al., 2014), which is

mainly due to the better established connection to human health effects. Nevertheless, there exist exposure assessments for the cities of Helsinki (Kousa et al., 2002) and Oslo (Baklanov et al., 2007), which both focus on the description and application of exposure modeling systems based on chemistry transport modeling. Nevertheless, in our study we used the metric of the annual total population exposure to present our results, while Baklanov et al. (2007) and Kousa et al. (2002) presented exposure averages for different time periods (e.g. afternoons in March) and metrics (e.g. number of persons exposed). Based on the reviewers suggestion, we decided to calculate the averaged afternoon exposure in March 2012, similarly to Kousa et al. (2002), to compare the results. Although Kousa et al. (2002) calculated the exposure for March 1996 based on emissions and meteorology specific for Helsinki, we hold this comparison for the meaningful, due to the application of a dynamic population activity with similar time profiles.

Thus, we followed Kousa et al. (2002) and calculated the results of the afternoon period (3 p.m.–6 p.m.) in March 2012 for the Riga domain, which is comparable in size and population density. The concentrations, activity and the resulting average exposure are calculated as average values in this time period; the corresponding numerical values of activity and average exposure in each grid cell therefore refer to the number of people (density of population), and the concentration times the number of people, respectively. Comparing the results for Riga with the same metric for a similar time shows similar values ranges and maxima for concentrations of NO₂, lower population densities per 100 x 100 m² and thus lower exposure values (Figure 1) as presented in Kousa et al. (2002; see figure 3 a-c).

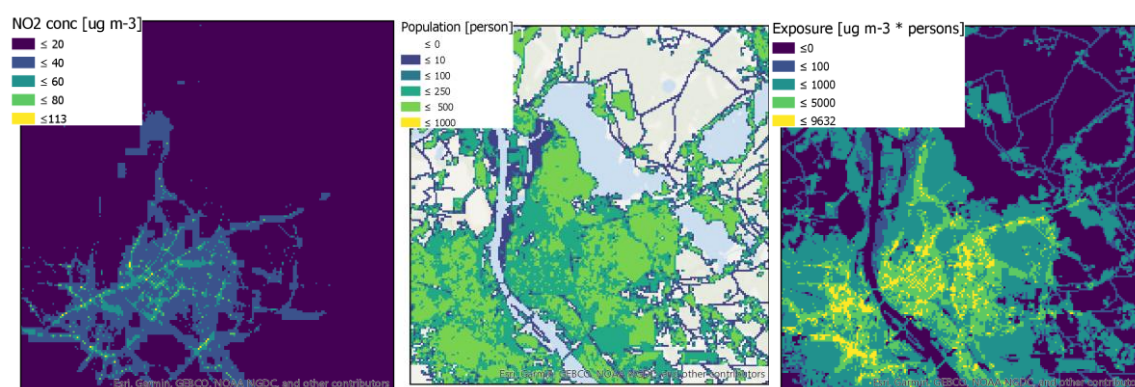


Figure 1: The predicted ambient air concentrations of NO₂ (ug m⁻³), the density of population (persons) and the average exposure of the population to NO₂ concentrations (ug m⁻³ * persons), evaluated for the afternoon time period, as an average value in March 2012 in Riga. The grid size is 100m x 100 m, the size of the depicted area is 20km x 20 km.

Differences in the concentration results can be explained with differences in the input data for city-specific emissions, meteorology and boundary conditions. The lower population density, especially in the centre of the city is mainly an effect of the uniform spatial distribution to Urban Atlas classes, which represent dense city areas but cannot represent real city-specific city centres.

This problem will be addressed in future studies by combining OSM points of interest, which can be characterized as city-centre features, to identify areas of high population density during the day. The exposure values are the cross product of concentration and population and thus, they are lower than they were calculated in the city of Helsinki. Nevertheless, it appears that exposure values as calculated within our study with the developed generic approach are solid in terms of spatial distribution.

R2.3. *“Uncertainties of the NMVOC and the impacts on NOx simulation should also be discussed.”*

Response to R2.3:

A section on the uncertainty of NMVOC emissions has been moved from the emission inventory section to the discussion section (see response to R1.1) including a discussion about the impacts of NMVOC on NOx simulation was added. In response 1.3 to reviewer 1 we added a revised section of the discussions chapter including uncertainty discussions.

R2.4. *“The uncertainties come from the different steps should be discussed too. For example, the EI, air quality model, exposure responses etc? [...], how about the sensitivity of the simulations?”*

Response to R2.4:

Please see response 1.3 to reviewer 1, in which we added a revised section of the discussions chapter including uncertainty discussions.

R2.5. *“Any seasonal or monthly differences for your results? Or during the shipping busy/non-busy periods [...]?”*

Response to R2.5:

The scope of this study is the development and application of a generic population exposure modeling approach, which can be applied to different sources of emissions; in this case shipping emissions. Therefore, the detailed description of temporal variation in concentration and exposure results would exceed the scope of this study. Moreover, results of population exposure calculations are mostly used to evaluate long-term health effects (Özkaynak et al., 2013) and therefore this study does not aim at discussing temporal variations. Nevertheless, it would be possible to evaluate seasonal and monthly differences in the concentration and exposure results as well as periods of busy and non-busy shipping activities due to calculated hourly concentrations and exposure. However, this is out of the scope of this study and will be part of future studies.

List of Minor changes requested by R2 have been considered in the final manuscript:

- “Page 1 Line 18, page 12 line 9: 100X100 functions should be used instead of letter x”
5 ○ **We exchanged the letter “x” with “×” for all resolution details in the manuscript.**
- “Page 18: NO₂ should use subscript.”
 ○ **We applied subscript for NO₂ on page 18.**

References

- 10 Aulinger, A., Matthias, V., Zeretzke, M., Bieser, J., Quante, M., and Backes, A.: The impact of shipping emissions on air pollution in the greater North Sea region - Part 1: Current emissions and concentrations, *Atmos. Chem. Phys.*, 16, 739–758, doi:10.5194/acp-16-739-2016, 2016.
- Baek, S.-O., Kim, Y.-S., and Perry, R.: Indoor air quality in homes, offices and restaurants in Korean urban areas—indoor/outdoor relationships, *Atmospheric Environment*, 31, 529–544,
15 doi:10.1016/S1352-2310(96)00215-4, 1997.
- Baklanov, A., Hänninen, O., Slørdal, L. H., Kukkonen, J., Bjergene, N., Fay, B., Finardi, S., Hoe, S. C., Jantunen, M., Karppinen, A., Rasmussen, A., Skouloudis, A., Sokhi, R. S., Sørensen, J. H., and v. Ødegaard: Integrated systems for forecasting urban meteorology, air pollution and population exposure, *Atmos. Chem. Phys.*, 7, 855–874, doi:10.5194/acp-7-855-2007, 2007.
- 20 Bieser, J., Ramacher, M. O. P., Prank, M., Solazzo, E., and Uppstu, A.: A Multi model study on the impact of emissions on CTMs, in: *Air Pollution Modeling and its Application XXVI: Springer Proceedings in Complexity*, Mensink, C., Gon, W., and Hakam, A. (Eds.), 2020.
- Borrego, C., Sá, E., Monteiro, A., Ferreira, J., and Miranda, A. I.: Forecasting human exposure to atmospheric pollutants in Portugal – A modelling approach, *Atmospheric Environment*, 43, 5796–
25 5806, doi:10.1016/j.atmosenv.2009.07.049, 2009.
- Chau, C.K., Tu, E.Y., Chan, D.W.T., and Burnett, J.: Estimating the total exposure to air pollutants for different population age groups in Hong Kong, *Environment international*, 27, 617–630, doi:10.1016/S0160-4120(01)00120-9, 2002.
- Dimitroulopoulou, C., Ashmore, M. R., Hill, M.T.R., Byrne, M. A., and Kinnersley, R.: INDAIR: A
30 probabilistic model of indoor air pollution in UK homes, *Atmospheric Environment*, 40, 6362–6379, doi:10.1016/j.atmosenv.2006.05.047, 2006.

- Gately, C. K., Hutyra, L. R., Peterson, S., and Sue Wing, I.: Urban emissions hotspots: Quantifying vehicle congestion and air pollution using mobile phone GPS data, *Environmental pollution* (Barking, Essex 1987), 229, 496–504, doi:10.1016/j.envpol.2017.05.091, 2017.
- 5 Kousa, A., Kukkonen, J., Karppinen, A., Aarnio, P., and Koskentalo, T.: A model for evaluating the population exposure to ambient air pollution in an urban area, *Atmospheric Environment*, 36, 2109–2119, doi:10.1016/S1352-2310(02)00228-5, 2002.
- Matthias, V., Arndt, J. A., Aulinger, A., Bieser, J., van der Denier Gon, H., Kranenburg, R., Kuenen, J., Neumann, D., Pouliot, G., and Quante, M.: Modeling emissions for three-dimensional atmospheric chemistry transport models, *Journal of the Air & Waste Management Association* 10 (1995), 68, 763–800, doi:10.1080/10962247.2018.1424057, 2018.
- Özkaynak, H., Baxter, L. K., Dionisio, K. L., and Burke, J.: Air pollution exposure prediction approaches used in air pollution epidemiology studies, *Journal of exposure science & environmental epidemiology*, 23, 566–572, doi:10.1038/jes.2013.15, 2013.
- 15 Requia, W. J., Higgins, C. D., Adams, M. D., Mohamed, M., and Koutrakis, P.: The health impacts of weekday traffic: A health risk assessment of PM_{2.5} emissions during congested periods, *Environment international*, 111, 164–176, doi:10.1016/j.envint.2017.11.025, 2018.
- Sillman, S.: The relation between ozone, NO_x and hydrocarbons in urban and polluted rural environments, *Atmospheric Environment*, 33, 1821–1845, doi:10.1016/S1352-2310(98)00345-8, 1999.
- 20 Smit, R., Brown, A. L., and Chan, Y. C.: Do air pollution emissions and fuel consumption models for roadways include the effects of congestion in the roadway traffic flow?, *Environmental Modelling & Software*, 23, 1262–1270, doi:10.1016/j.envsoft.2008.03.001, 2008.
- Soares, J., Kousa, A., Kukkonen, J., Matilainen, L., Kangas, L., Kauhaniemi, M., Riikonen, K., Jalkanen, J.-P., Rasila, T., Hänninen, O., Koskentalo, T., Aarnio, M., Hendriks, C., and 25 Karppinen, A.: Refinement of a model for evaluating the population exposure in an urban area, *Geosci. Model Dev.*, 7, 1855–1872, doi:10.5194/gmd-7-1855-2014, 2014.