Response to reviewer comment #2

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Title: The impact of ship emissions on air quality and human health in the Gothenburg area – Part II
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Point 1: This study conducted simulations to assess the impact of ship emissions on air quality over the Gothenburg area, as well as their health impacts between 2012 and 2040. The manuscript is well written and organized. I recommend this manuscript to be published if the comments are addressed.

Response to point 1: We thank the Reviewer for providing a detailed evaluation of our study, the manuscript and the helpful comments and suggestions regarding the methodology used in our study.

Point 2: Please add general descriptions of Gothenburg, including its graphical locations. Moreover, please add longitudes, latitudes and geographical information for all the spatial distribution maps in the manuscript.

We thank the reviewer for pointing out the need to further describe research domain in the part II manuscript. Therefore, we decided to add a figure of the research domain in the part II manuscript, and add some general information on the Gothenburg urban area. Due to the density of information, which is already provided in all contour plots in the manuscript, we decided not to add geographical references or administrative boundaries. Nevertheless, the additional figure on the research domain shall give guidance to recognize underlying geographical characteristics.

The following was added to the manuscript in a new section 2.1 on Gothenburg:

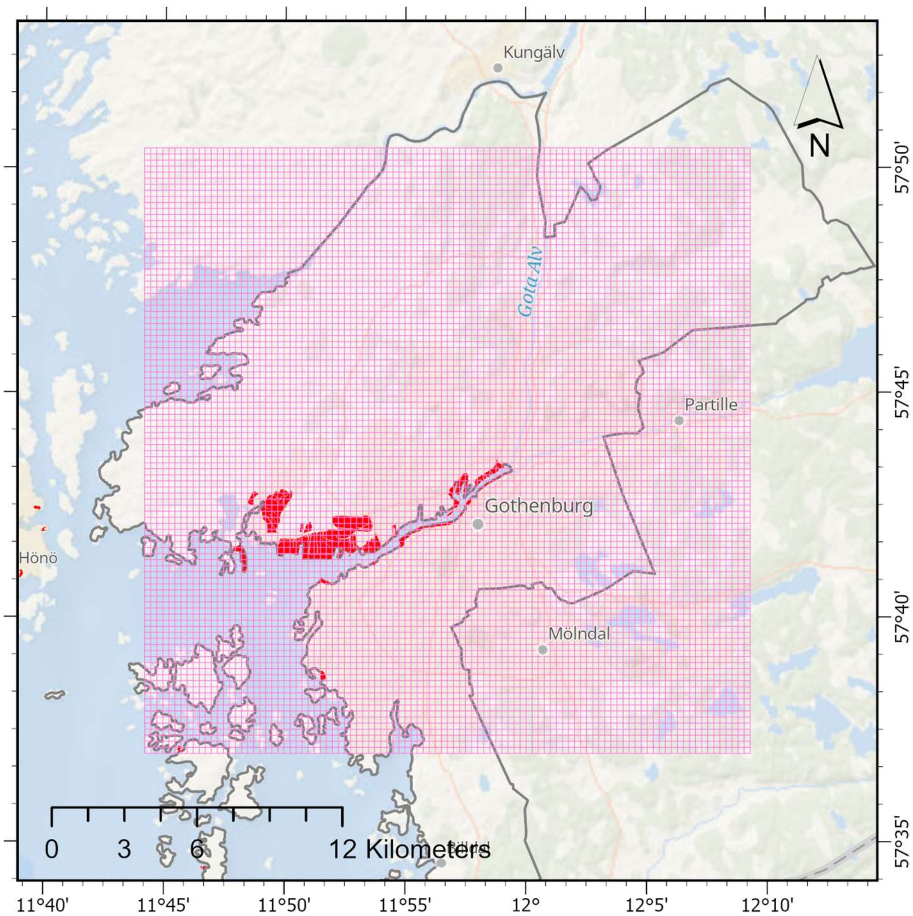


Figure 1: The Gothenburg research domain. The light red grid indicates the domain extent and the horizontal grid-cell size of 250m. Red areas indicate port areas and grey lines indicated the city boundaries as given by the Copernicus Urban Atlas 2012 dataset. Maps are created with ArcGIS with underlying basemap sources Esri, HERE, Garmin, GEBCO, National Geographic, NOAA, and GIS User Community.

"The city of Gothenburg is located on the western coast of Sweden, with about 0.57 million inhabitants and an area of 450 km2. The dominant wind direction in Gothenburg is south-west with average wind speed of 3.5 m s-1, indicating the major transport path from sea to the land, especially in summer. The geomorphology of the Gothenburg area is described as a fissure valley landscape dominated by a few large valleys in north-south and east-west directions. The major air pollution sources in Gothenburg are above all road traffic and industry, wood burning, shipping, agriculture, working machines and long-range transport (LRT) from the European continent and other parts of Sweden. The harbour and shipping activities are important emission sources and directly influences the urban air quality. The centre of the city is situated on the southern shore of the river Göta älv. The Port of Gothenburg receives between 6,000 and 6,500 calls per year and additional 600–700 ships pass to and from ports upstream and on the Göta älv. The port annually handles approximately 900,000 containers, 20 million tonnes of petroleum, and half a million Roll-on/roll-off (RoRo) units (Winnes et al., 2015). Passenger traffic in Gothenburg is also very busy with 1.5 million passengers who ferry to and from Gothenburg to Denmark, Germany etc. on Stena Line ferries each year. This makes the port the largest cargo port in Scandinavia. Annual analyses of air quality monitoring data Environmental Administration of City of Gothenburg show exceedances of both the target and the limit values for NO2 at several stations in Gothenburg in 2012 with decreasing trends towards exceedances of only the limit value at traffic stations in 2019. For PM10 the levels were well below the limit value but exceeding the target value in 2012 without any significant trend towards presence with exception of the urban background where slightly decreasing trend have been observed and the annual mean was bellow the target value of 15 µg/m³ the last 4 years. The measured concentration levels of PM2.5 have been bellow the target value without any significant trend at Gothenburg monitoring stations. Concentrations of ozone have a slightly increasing trend from year 2012 onwards and tend to exceed the limit values for maximum hourly and 8-h means at a number of occasions each year (Miljöförvaltningen, 2019)."

Point 2: This study adopted meteorological field of 2012 in the simulation. The diffusion conditions may influence the impacts of emission reduction on air quality. So please add descriptions of the meteorological fields of 2012 to describe whether it is a year with good diffusion conditions or not. I suggest selecting a year of which the meteorological conditions are close to the climatological conditions, and then conduct the simulation.

Response to point 2: We thank the Reviewer for pointing out the need to clarify our decisions for the meteorological base year. This study has been conducted within the BONUS SHEBA project (Shipping and Environment of the Baltic Sea Region) where the impact of current and scenario emissions from ships on air quality have been investigated as a part of a holistic assessment framework for impacts of shipping on marine and coastal environment. The shipping-related air pollution has been investigated on a range of spatial scales with several chemistry-transport models: coarse spatial scale resolution was used for simulations in the European domain, finer resolution was used for the Baltic Sea (Karl et al., 2019b; Karl et al., 2019a), and city-scale simulations using high spatial resolution were used for several harbour cities (Ramacher et al., 2019). The present study (Part I) evaluates the contributions of regional and local shipping to the concentrations of SO_2, NO_2, $PM_{2.5}$, O_3 and secondary PM, as well as the human exposure and the associated health impacts in Gothenburg for year 2012.

All studies conducted are based on the reference year 2012. Based on the temperature anomalies and precipitation anomalies for the decade 2004–2014 for Baltic Proper, the year 2012 was chosen as the meteorological reference year for the CTM simulations in Part I of the Gothenburg study as well as in regional studies for current (2012) and future (2040) conditions and shipping scenarios. Year 2012 anomalies for 2 m temperature (±2 ∘C) and total precipitation (±25 mm) were closely aligned with the decadal average of the 2004–2014 period. The meteorological year 2012 was also used in CTM calculations of the future air quality situation to avoid complication of the interpretation of changes between the present-day and the future.

We added the information on 2012 representing a reference year for the region to the manuscript:

"Based on the temperature anomalies and precipitation anomalies for the decade 2004–2014 for Baltic Proper, the year 2012 was chosen as the meteorological reference year for the CTM simulations in Part I of the Gothenburg study as well as in regional studies for current (2012) and future (2040) conditions and shipping scenarios (Karl et al. 2019, Tang et al. 2020)."

Point 3: In Section 5, this study assessed the impact of future shipping on human health, including premature deaths because the decrease of ambient PM2.5, O3, and NO2. Exposures to PM2.5, NO2, and O3 can all lead to premature deaths due to respiratory diseases. So in Table3, I am wondering whether there are overlaps between the number of premature deaths due to PM2.5 with those due to NO2 and O3.

Response to point 3: We thank the reviewer for this comment. The health impact are presented for each pollutant separately and these impacts are not additive, In methodology part of Part 1 of this study (Tang et al., 2020) we state:

"The health impacts of some pollutants are correlated and that is why the premature deaths attributed to each pollutant cannot simply be added up. In particular, it has been estimated that adding premature deaths attributed to $PM_{2.5}$ to those attributed to NO_2 could result in double counting of around 30 % (WHO 2013a)."

Point 4: Minor comments.

Response to point 4: Minor comments are answered hereunder.

1. P6 Line10-15: Add more information for the simulation, including a figure to present the domains of the simulation, the period of the simulation, model spin-up, etc.

We added a new figure to the manuscript as introduced in our response to point 1. Additionally we added information on the model setup in the supplement, due to this information mostly given in the accompanying part 1 publication:

"

Table S4-1: City-scale model setup.

	Domain	Spatial resolutions	Model / Database
Meteorology 2012	30 km × 30 km	500 m	ECMWF ERA5 0.3° × 0.3°, 21 layers
Background concentrations	160 km × 96 km	4 km × 4 km	CMAQ
Local shipping emissions 2012	30 km × 30 km	250 m × 250 m	STEAM2
Local traffic emissions 2012	30 km × 30 km	meters (line sources)	Miljöförvaltningen and HBEFA v. 3.2
Local industrial, machines, wood burning and aviation etc. 2012	30 km × 30 km	1 km × 1 km	SMED

The period of the simulation is the year 2012 (introduced in the manuscript) and due to the rather fast chemistry on urban-scales, there is no model spin-up necessary. Tests with and without a model spin-up time of one week have shown differences in results below 0.1% for the first hours of simulated concentrations in the simulation period."

2. Cite Figure 1 in the manuscript, or delete it.

Figure 1 is now cited in the manuscript in 2.3.

3. Please show the spatial distribution of the emission inventories of 2012.

The spatial distribution of local shipping emissions has been shown in Paper I, which will be included in the supplement.

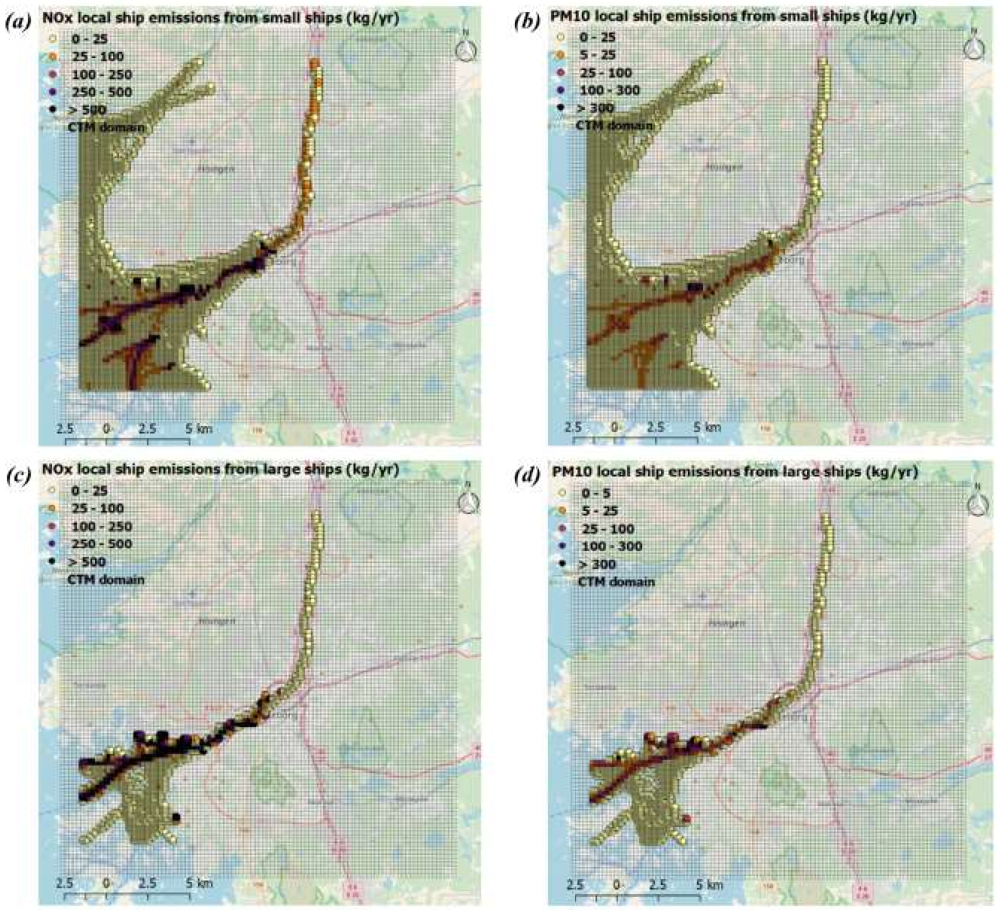
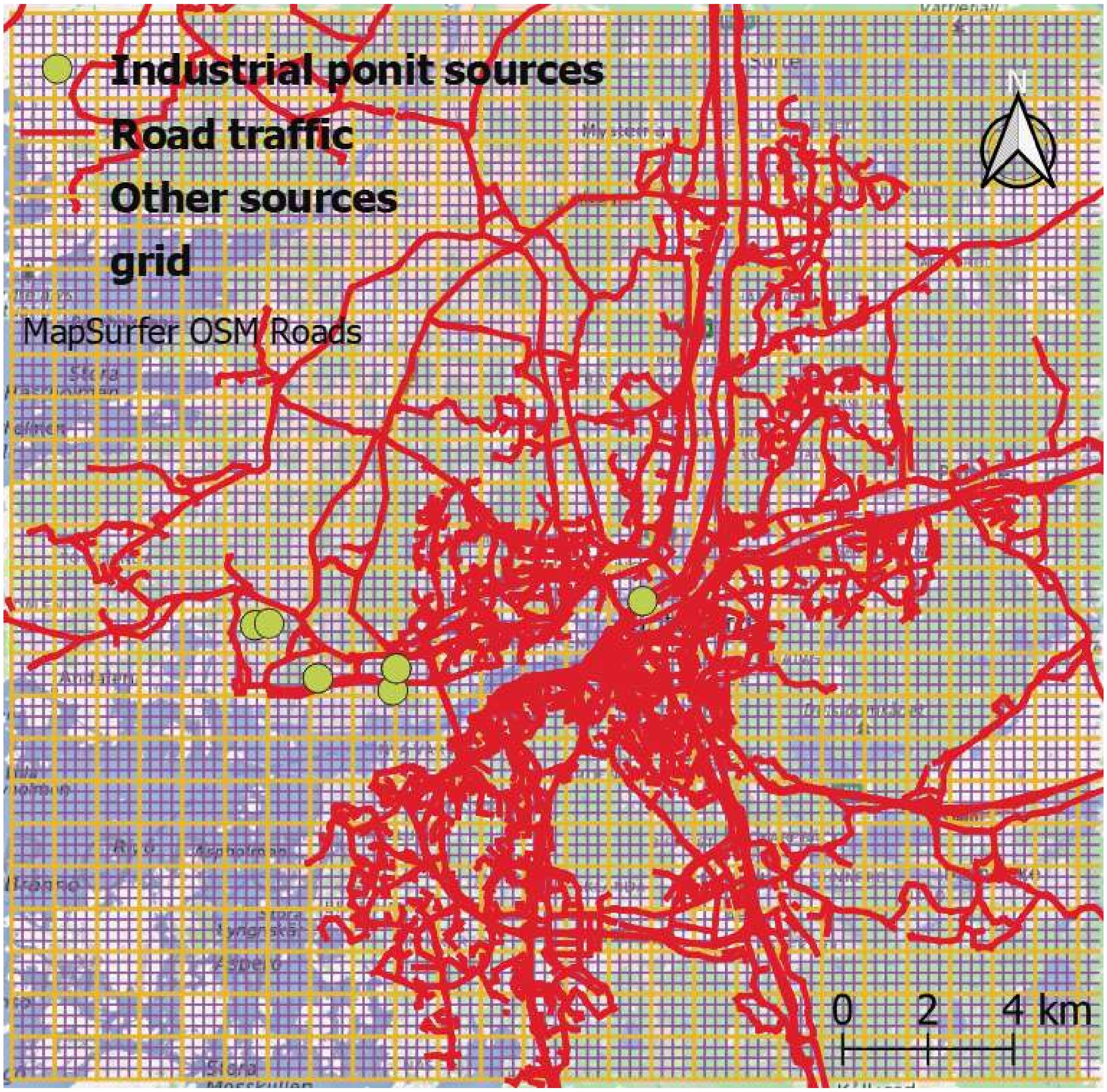


Figure 2. Annual local shipping emissions of **(a)** NO_x and **(b)** PM_{10} (equal to $PM_{2.5}$) from small vessels with a stack height below 36 m (assumed 15 m) and **(c)** NO_x and **(d)** PM_{10} from large vessels with high stack height above 36 m (assumed 36 m) in the Gothenburg area. Base map credits: © OpenStreetMap contributors 2020. Distributed under a Creative Commons BY-SA License.

Moreover, the following figure shows the spatial distribution of local emissions from road traffic and industrial point sources. In addition, other emissions such as domestic heating, working and off-road machinery etc. expressed as grid sources in the model. The map on spatial distribution of emissions is now included in the supplement.



The spatial distribution of local emissions from road traffic (red lines), industrial point sources (green circles), and other sources (yellow lines).

4. In Figure 4, the unit for figure in row3 column 3 should be ug/m3; the unit for figure in row3 column 4 should be %.

We changed the figure accordingly. Thank you for your detailed examination of our manuscript.

References

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