Supplement to

The ELK global emission inventory for the transport sector.

1 Methodical details: Land transport

Here we compare the spatial disaggregation method applied for the global land transport inventory with an alternative method for Europe based on the ULTIModel (see Sect. 2.1.4 in the main text).

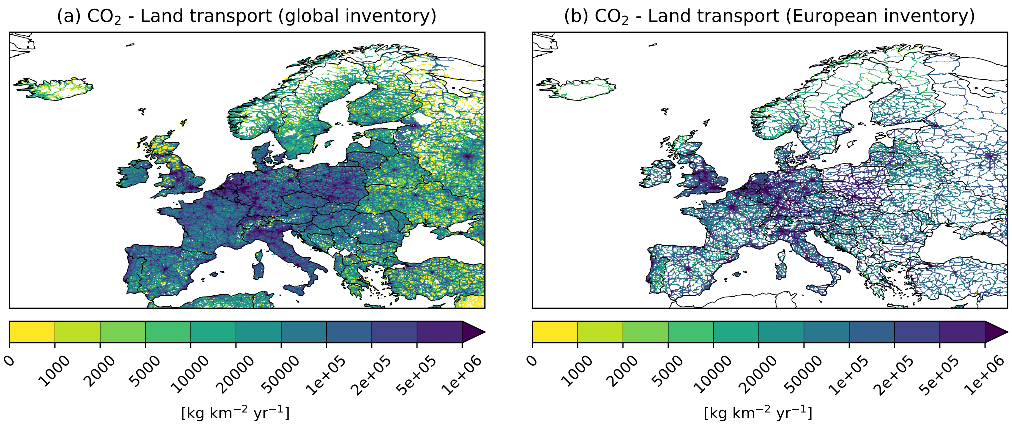


Figure S1: CO_2 emissions of the land transport sector in Europe in the global inventory (a) and in the European inventory based on the ULTIModel (b).

Species	Global inventory	European inventory
BC	0.064	0.055
CH_4	0.058	0.033
CO	5.184	4.762
CO_2	1175.291	1114.484
CO_2-total	1254.277	1191.909
HC	0.362	0.222
N_2O	0.037	0.035
NH_3	0.105	0.102
NMHC	0.295	0.189
NO_2	0.739	0.655
NO_x	3.832	3.463
OC	0.030	0.022
PM_{10}	0.102	0.085
PM_{10}-brakewear	0.037	0.037
PM_{10}-tirewear	0.048	0.046
$PM_{2.5}$	0.097	0.085
$PM_{2.5}$-brakewear	0.014	0.014
$PM_{2.5}$-tirewear	0.034	0.032
PN	7.66×10^{25}	6.92×10^{25}
PN-brakewear	1.79×10^{24}	2.51×10^{24}
SO_2	0.010	0.010

Table S1: Aggregated emissions of the land transport sector in Europe in the global inventory and in the European inventory generated using the ULTIModel. Units are Tg(species), Tg(NO_2) for NO_x and particles for PN.

Methodical details: Energy for transport In addition to the overview of the applied methodology in the main text, we provide here a detailed description of the methods used to calculate indirect emissions from the transport sector. First, we go into detail regarding the estimation of total emissions of global refineries in the year 2019. Second, we show how we determined the transport-induced share of refinery products on country-level. Finally, we describe how we apply the transport-induced share to the total refinery emissions to determine the final result, refinery emissions from transport activities.

1.1 Refinery-level emission data

We determine emissions for 85 global countries and 549 refineries. According to the extended energy balances, 20 more countries register refinery output. They could not be considered due to missing data on existing refineries in these countries. However, these 20 countries only make up 0.15 - 0.25 % of the total global emissions, depending on the species and can therefore be considered negligible on a global scale.

1.1.1 Refinery-level reports

In the EU, the United States and in Canada, reported refinery emission data are available. Since they are usually considered of high quality and also provide the geolocations of plants, they are prioritized over estimating emissions with activity data and emission factors for the determination of refinery-level emissions for the year 2019.

Europe To get emissions for refineries in the EU, we use the 2019 reported emission data for the E-PRTR sector 1(a) (Mineral oil and gas refineries) from the E-PRTR reporting scheme. These reports, however, include total emissions from EU facilities without distinguishing between emissions from combustion or other process activities. Therefore, an additional factor from Sun et al. (2019)[1] is applied to the reported emissions in order to be consistent with the other emission data and to account only for emissions from fuel combustion as defined in the main text. The data published by Sun et al. (2019) differentiate the shares of three sources (combustion, process and facility-wide emissions) of emissions from US refineries in 2014 for each species. The only species not targeted in the paper is Black Carbon, for which the shares of $PM_{2.5}$ are used. Since the E-PRTR reports only contain emissions above a species-specific threshold defined in Annex 1 of the EU directive 166/2006, not all species are available for all refineries. To also account for missing species, a gap-filling routine is established (see below). BC and $PM_{2.5}$ is not reported in the E-PRTR data. Their emission values are derived from the reported PM_{10} emissions and the $PM_{2.5}/PM_{10}$ and BC/PM_{10} proportions of the EMEP/EEA guidebook 2023 default emission factors from sector 1A1b (`https://www.eea.europa.eu/publications/emep-eea-guidebook-2023`, last access: 2 October 2024).

United States For industrial facilities in the US, reported emission data are available for emissions from the years 2017 and 2020 for the sector description 'Petroleum refineries' (`https://www.epa.gov/air-emissions-inventories/2017-national-emissions-i`

[1]Sun, P., Young, B., Elgowainy, A., Lu, Z., Wang, M., Morelli, B., and Hawkins, T.: Criteria Air Pollutant and Greenhouse Gases Emissions from U.S. Refineries Allocated to Refinery Products, Environ. Sci. Technol. 53, 6556-6569 doi:10.1021/acs.est.8b05870, 2019

nventory-nei-data#doc, last access: 2 October 2024). Although the year 2020 is closer to the targeted year 2019 for the emission inventory, the data from 2017 are used due to possible deviations in refinery activities in 2020 caused by the Covid pandemic. In order to account for the difference of refinery activities in 2019 compared to the reported emission data from 2017, a 0.4 % decrease in crude oil consumption in refineries was considered on all emission values, based on consumption data from the energy balances for the US. To determine black carbon emissions, the emission values for elemental carbon are used as suggested by the US EPA (https://www.epa.gov/air-emissions-inventories/how-does-pm25-relate-pm-species-such-ec-oc-so4-no3-pmfine-and-diesel-pm25, last access: 2 October 2024). Similar to the EU refinery reported emission data, the factors taken from Sun et al. (2019) are used to obtain only emissions from combustion processes (see previous subsection Refinery-level emission data - Europe).

Canada Also for Canada, reported emission data on refinery level (NAICS 6 Code: 324110) for the year 2019 are available for all species except CO_2 (https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/air-pollutant-emissions.html,accessed02.10.2024;https://climate-change.canada.ca/facility-emissions/, last access: 2 October 2024). As opposed to the reporting schemes of industrial facilities in the EU and US, the Canadian reports differentiate between five emission sources: stack, storage and handling, fugitive, spills, and others. It was assumed that stack emissions include emissions from refining processes and from combustion. Since we consider only emissions from combustion in the inventories, the share of emissions which can be attributed to process emissions is deducted for each species, based on the data published by Sun et al. (2019), as described above for European emission data. BC is not reported by the Canadian datasets, so the emission values are derived from the $BC/PM_{2.5}$ share of the EMEP/EEA guide 2023 default emission factors for all fuels from sector 1a1b (https://www.eea.europa.eu/publications/emep-eea-guidebook-2023, last access: 2 October 2024). For CO_2, another dataset focusing on greenhouse gases from refineries in Canada is used (source). Matching the two datasets is possible thanks to the same plant IDs in both sources.

Refinery-level gap filling routine Regarding the reported refinery emission data from Canada, the EU countries and the US, not all species are reported for each refinery. These gaps appear due to emission thresholds defined by the respective authorities which oblige refinery operators to only report emissions if they exceed a specific emission threshold. In order to still be able to account for these emissions and fill the emission gaps, we establish a gap-filling routine based on the available emission values. As a first step, the emission ratio between all non-CO_2 species and CO_2 are calculated for the Canada, US and EU datasets separately. For these ratios, only refinery-level reports which contain both the non-CO_2-species emissions and CO_2 emissions are considered in order to avoid distortions. These ratios are then used to derive missing reports for non-CO_2 species from given CO_2 emissions. In case CO_2 emissions are not reported, they are derived from NO_x, SO_x, PM_{10} and NMVOC emissions in descending preference using the emission ratios calculated before.

1.1.2 Country-level reports

For some countries, reported country-level GHG and air pollutant emission data from the CLRTAP and UNFCCC emission reporting channels are available. From both sources, we use the emission data for the year 2019 from the 2023 submissions. In comparison to earlier submissions which also include the year 2019, the 2023 submissions often include improved emission data for 2019, e.g., due to enhanced methodologies. From these reports, emission data for the chosen emission species from the IPCC emission sector 1a1b (fuel combustion activities from petroleum refining) are used to determine country-level emissions from petroleum refining. No correction is necessary to only account for emissions from combustion, since sector 1a1b only refers to combustion emissions.

Country-level gap-filling routine In many cases, not all considered species for the emission inventories are available in the country-level reports. Thus, a gap filling routine is established to derive the missing emission quantities. Since different countries use different fuels to operate refineries, we include this information from the extended energy balances. As a first step, fuel-specific emission ratios are calculated from the EMEP/EEA emission guidelines for sector 1a1b. Afterwards, we determine the shares of each fuel from total fuel consumption in refineries from the energy balances in order to account for country-specific fuel consumption in refineries. Lastly, we use the fuel-specific emission ratios and the country- and fuel-specific consumption ratios to obtain consumption-weighted fuel- and country-specific emission ratios which are then used to derive species which are not available in the reported data.

1.1.3 Country-level emission calculation

For all countries where no reported refinery-level or country-level emission data are available, we calculate emissions on country-level based on fuel consumption data from the energy balances and default emission factors from the EMEP/EEA guidelines 2023 for energy industries as described below. There is one exception, India, for which country-specific emission factors are determined for some species and multiplied with the consumption data from the energy balances.

India For India, we can derive country-specific emission factors for SO_2, NO_x, PM_{10} and CO based on emission limits for the refinery sector. Since, according to , only natural gas and refinery gas is consumed in Indian refineries, only the emission factors for gas are considered. The emission factors are defined as a concentration and are therefore converted to mass-per-energy unit using an oxygen concentration of 3 %. To derive $PM_{2.5}$ and BC emissions, the shares of the emission factors for $PM_{10}/PM_{2.5}$ and PM_{10}/BC from the EMEP/EEA guidelines are applied. For CO_2 and NMVOC, the default emission factors from the EMEP/EEA guidelines are used. All emission factors are multiplied with activities for the refinery sector in 2019.

1.1.4 Default emission calculation

Activity data The activity data for the default calculation of country-level refinery emissions are based on the country-level refinery fuel consumption for the year 2019 from the extended energy balances. The fuel types given in the energy balances do not exactly match the fuel types for which emission factors are available. Thus, for some fuels, the emission factors of a similar fuel is used, as shown in S2.

Emission factors For the default emission calculation, we use the emission factors from the EMEP/EEA guidelines from 2023 (`https://www.eea.europa.eu/publications/emep-eea-guidebook-2023`, last access: 2 October 2024) for sector 1A1B (Combustion of fuels - petroleum refining) for all species except CO_2. For CO_2, the default emission factors from the IPCC 2006 Guidelines for National Greenhouse Inventories for stationary combustion are applied using the same fuel types as for the emission factors from the EMEP/EEA guidelines described in S2 (`https://www.ipcc.ch/report/2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/`, last access: 2 October 2024)

Emission calculation without activity data For some countries, the extended energy balances show refinery activities in form of crude oil input, but no activities regarding the fuel consumption within refineries. Thus, no default emission calculation as described above is possible. In this case, emission factors for all species are calculated based on the previously determined, aggregated emissions of all global refineries from the previous methods (i.e., refinery-level and country-level reports as well as the default emission calculation) relative to the aggregated crude oil input into refineries from all countries in the energy balance database. Since crude oil input is given in the countries without refinery consumption, the missing emissions can be approximated with this method.

1.1.5 Spatial distribution

In case country-level emissions reports are used or emissions are calculated with the default approach, emissions are only available on country level. To use these data in the inventories, they have to be distributed to refinery-level. We use a global crude oil refinery list by the Global Energy Observatory which comprises the geolocation and crude oil processing capacity for 513 global refineries and was last updated in 2018 (`https://globalenergyobservatory.org/list.php?db=Resources&type=Crude_Oil_Refineries`, last access: 20 August 2024). Country-level emissions are spatially distributed based on the processing capacity. For some countries, no refineries are included in the dataset. With manually researched geolocations and capacities of refineries for the countries with the highest country emissions among the countries lacking refineries, we are able to spatially distribute more than 99 % of CO_2 emissions.

1.2 Transport-induced refinery products

Although a large share of refinery products is eventually consumed in the transport sector, there are also other sectors which make use of products from oil refining. In order to determine the transport-induced refinery emissions, it is necessary to determine the share of transport-relevant refinery products (i.e., fuels) which are actually induced by the transport sector. We approach the determination of the share of transport fuels in two ways which we describe in detail in the following sections. First, for each country with refining activities according to , we calculate how much of their refinery output is consumed for domestic transportation. Second, we also determine the quantity of refinery products which are used in the transport sector of other countries. Then, we add up

fuel type	Emission factors used
Refinery gas	Refinery gas
Coke oven gas	Refinery gas
Natural gas	Natural gas
LPG	Natural gas
Fuel oil	Residual oil
Petroleum coke	Residual oil
Other oil products	Residual oil
Gas/diesel oil	Gas oil

Table S2: Considered fuel types and corresponding fuel types from which emission factors are used

the domestic and exported amount of fuel used in the transport sector and divide it by the total refinery output quantity. This approach allows us to determine the proportion of fuels consumed in the transport sector relative to the total amount produced in each country. In the following, we go into the details of this methodology.

Domestic transport-induced refinery products The domestic share of refinery output used in the transport sector is based on data from the energy balances. For each refinery product relevant to the transport sector, we use the produced quantity in the year 2019 (line 26 of the energy balance tables) in each country and determine how much thereof is consumed in the domestic transport sector. We do so by determining a proxy which describes the share of transport consumption (line 68) to total consumption (line 52) and multiplying this share with the aforementioned produced quantities of each fuel. This results is the domestic consumption of produced fuels from refineries.

Exported amounts of refinery fuels The consumption of fuels from domestic refineries in other countries relies on the results of the previous step. First, the difference between the total domestic production and the domestic consumption in the transport sector is calculated. If the domestic consumption is higher or equal than the domestic production, we assume there is no fuel remaining for exports. If the production is higher than the domestic consumption, we use trade shares from Eurostat and Comtrade (see next paragraph) to calculate how much of the remaining fuel quantity is exported to which countries.

Determination of imported fuel amounts with trade shares (Eurostat, Comtrade) Once it is known how much fuel of a country is exported, we need to determine which countries these products are exported to in a second step. We estimate this using country-level trade data from Eurostat (for EU countries) and Comtrade (for non-EU countries) for the year 2019. Since the fuel types of the and the Harmonized System (HS)-codes of product classification in the trade data do not match, we first have to determine the corresponding HS-codes of the considered fuel types. The Eurostat data comprise more detailed 8-digit HS-codes while the Comtrade data provide trade data in 6-digit HS-codes. Only part of the total exported fuel amount is consumed in the transport sectors of the importing countries. Thus, for each importing country, we multiply the imported fuel quantity with the fuel-specific share of transport consumption to total consumption calculated from the energy balances, to obtain only the import quantity used for transportation purposes.

fuel type		8-digit HS codes		6-digit HS codes
Gasoline	Motor spirit	27101241	Light oils	271012
		27101245		
		27101249		
Gas/diesel oil	Gas oils	27101943	Medium oils	271019
		27101946		
		27101947		
		27101948		
		27102011		
		27102016		
		27102019		
Fuel oil	Fuel oils	27101951	Heavy oils	271020
		27101955		
		27101962		
		27101966		
		27102032		
		27102038		
LPG	Propane	27111211	Propanes	271112
	Butane	27111330	Butanes	271113
		27111391		
		27111397		
		27111310		
Kerosene	Kerosene type jet fuel	27101921	Medium oils	271019

Table S3: Considered fuel types and their corresponding HS-codes from Eurostat and Comtrade trade data

1.3 Distribution of emissions to refinery products

In order to combine the information on transport-relevant fuels actually used in the transport sector and the total emissions of each species on refinery level, we still need to know how the total refinery emissions can be allocated to the transport-relevant fuels. For the distribution of refinery emissions to refinery products, information from the energy balances are used. They reveal the total product slate and their production quantities of each country with refinery activities based on energy content. As a first step, the energy content of all refinery products is aggregated for each country. Then, we divided the energy content of each refinery product by this aggregated energy content to get product-specific shares of the total refinery output. This is used as a basis for the following step, the distribution of total refinery emissions to each refinery product, including fuels relevant for the transport sector.

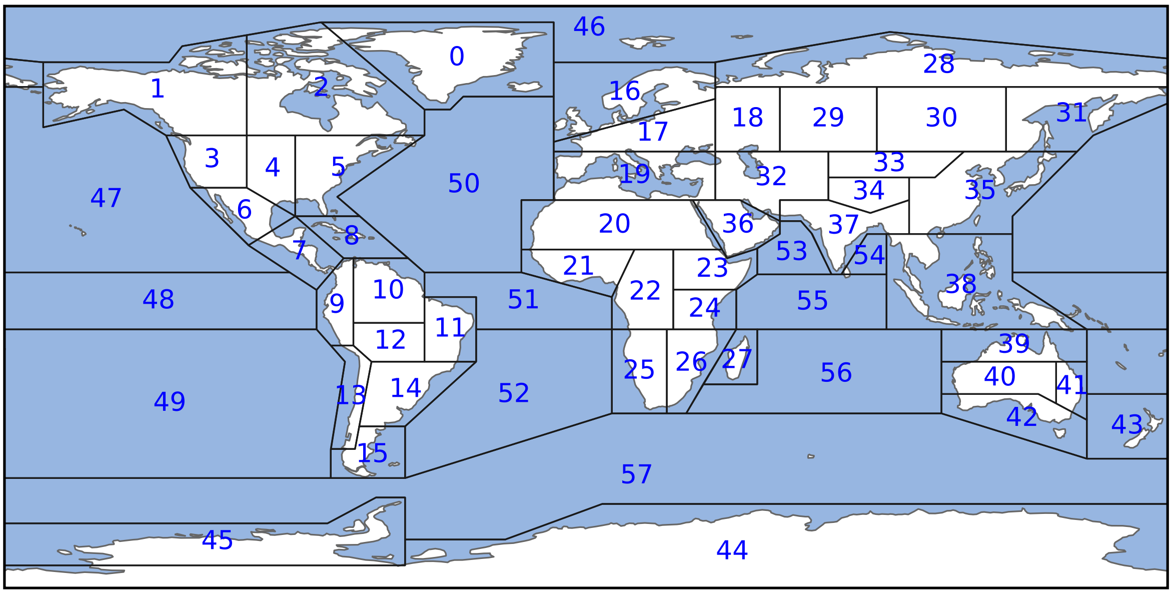
1.4 Transport-induced refinery emissions

In the final step, the total emissions on refinery level, the country-level shares of transport-induced refinery products and the country-level shares of individual refinery products from total refinery products are combined to calculate transport-induced emissions on refinery level. For each refinery, the total emissions of each species are distributed to individual refinery products (see 1.3) to get the refinery-level emissions of fuels relevant in the transport sector. Since these fuels are also used in other industries, the share of each fuel consumed in the transport sector is multiplied with the refinery-level fuel-specific emissions. These are then aggregated for each refinery and species to get the final result, the transport-induced refinery-level emissions from combustion processes.

1.5 Monthly temporal resolution

To the authors' knowledge, there is no specific temporal profile for refineries available to distribute yearly emissions to monthly emissions. Since land transport accounts for about 75 % of the transport sector's fuel consumption, we use the temporal monthly profiles of land transport as a proxy for the distribution of yearly to monthly emission data (https://.blob.core.windows.net/assets/52f66a88-0b63-4ad2-94a5-29d36e864b82/KeyWorldEnergyStatistics2021.pdf, last access: 2 October 2024). For this, we use data from Crippa et al. (2000)[2] who differentiate 23 global regions in their monthly temporal profiles (https://doi.org/10.6084/m9.figshare.12052887, last access: 2 October 2024).

[2]Crippa, M., Solazzo, E., Huang, G., Guizzardi, D., Koffi, E., Muntean, M., Schieberle, C., Friedrich, R. and Janssens-Maenhout, G: High resolution temporal profiles in the Emissions Database for Global Atmospheric Research, Sci. Data, 7, 121, doi:10.1038/s41597-020-0462-2, 2020



0: Greenland/Iceland
1: N.W.North-America
2: N.E.North-America
3: W.North-America
4: C.North-America
5: E.North-America
6: N.Central-America
7: S.Central-America
8: Caribbean
9: N.W.South-America
10: N.South-America
11: N.E.South-America
12: South-American-Monsoon
13: S.W.South-America
14: S.E.South-America
15: S.South-America
16: N.Europe
17: West&Central-Europe
18: E.Europe
19: Mediterranean
20: Sahara
21: Western-Africa
22: Central-Africa
23: N.Eastern-Africa
24: S.Eastern-Africa
25: W.Southern-Africa
26: E.Southern-Africa
27: Madagascar
28: Russian-Arctic
29: W.Siberia
30: E.Siberia
31: Russian-Far-East
32: W.C.Asia
33: E.C.Asia
34: Tibetan-Plateau
35: E.Asia
36: Arabian-Peninsula
37: S.Asia
38: S.E.Asia
39: N.Australia
40: C.Australia
41: E.Australia
42: S.Australia
43: New-Zealand
44: E.Antarctica
45: W.Antarctica
46: Arctic-Ocean
47: N.Pacific-Ocean
48: Equatorial.Pacific-Ocean
49: S.Pacific-Ocean
50: N.Atlantic-Ocean
51: Equatorial.Atlantic-Ocean
52: S.Atlantic-Ocean
53: Arabian-Sea
54: Bay-of-Bengal
55: Equatorial.Indic-Ocean
56: S.Indic-Ocean
57: Southern-Ocean

Figure S2: Map of the 58 world regions defined for the sixth IPCC assessment report (AR6) by Iturbide et al. (2020) and used for the analysis of the ELK emissions in comparison with other inventories.

2 Results: Land transport

Species	Total land transport		Cars		LCV		HFT	
BC	0.46	(100 %)	0.06	(13.27 %)	0.09	(19.77 %)	0.19	(40.50 %)
CH_4	0.86	(100 %)	0.10	(12.00 %)	0.02	(1.84 %)	0.06	(7.43 %)
CO	46.82	(100 %)	20.53	(43.85 %)	5.32	(11.35 %)	4.22	(9.01 %)
CO_2	6638.60	(100 %)	2980.00	(44.89 %)	594.94	(8.96 %)	2100.32	(31.64 %)
CO_2-total	7382.04	(100 %)	3321.00	(44.99 %)	635.99	(8.62 %)	2461.31	(33.34 %)
HC	4.97	(100 %)	0.72	(14.49 %)	0.08	(1.54 %)	0.62	(12.48 %)
N_2O	0.28	(100 %)	0.06	(23.03 %)	0.01	(5.01 %)	0.13	(45.61 %)
NH_3	0.69	(100 %)	0.54	(78.00 %)	0.04	(5.13 %)	0.10	(15.22 %)
NMVOC	8.50	(100 %)	0.61	(7.12 %)	0.06	(0.72 %)	0.52	(6.14 %)
NO_2	3.14	(100 %)	0.91	(28.84 %)	0.52	(16.51 %)	1.06	(33.56 %)
NO_x	25.51	(100 %)	3.77	(14.78 %)	2.08	(8.14 %)	14.10	(55.26 %)
OC	0.32	(100 %)	0.04	(11.53 %)	0.02	(7.33 %)	0.06	(19.42 %)
$PM_1$0	0.94	(100 %)	0.10	(10.72 %)	0.13	(13.54 %)	0.34	(35.92 %)
PM_{10}-brakewear	0.22	(100 %)	0.09	(42.20 %)	0.02	(8.78 %)	0.10	(45.56 %)
PM_{10}-tirewear	0.24	(100 %)	0.12	(50.06 %)	0.02	(9.99 %)	0.08	(34.05 %)
$PM_{2.5}$	0.75	(100 %)	0.10	(13.43 %)	0.13	(16.95 %)	0.34	(44.63 %)
$PM_{2.5}$-brakewear	0.08	(100 %)	0.03	(42.09 %)	0.007	(8.01 %)	0.04	(47.12 %)
$PM_{2.5}$-tirewear	0.16	(100 %)	0.09	(52.23 %)	0.02	(9.42 %)	0.05	(31.44 %)
PN	4.05×10^{26}	(100 %)	9.47×10^{25}	(23.39 %)	1.03×10^{26}	(25.50 %)	1.96×10^{26}	(48.32 %)
PN-brakewear	8.30×10^{24}	(100 %)	4.89×10^{24}	(58.95 %)	7.01×10^{23}	(8.45 %)	1.01×10^{24}	(12.16 %)
SO_2	1.01	(100 %)	0.35	(34.71 %)	0.14	(13.72 %)	0.51	(50.86 %)

Species	Buses		2-wheelers		Rail (passenger)		Rail (freight)	
BC	0.01	(2.10 %)	0.04	(8.10 %)	0.003	(0.58 %)	0.07	(15.68 %)
CH_4	0.004	(0.41 %)	0.65	(74.93 %)	0.008	(0.98 %)	0.02	(2.41 %)
CO	0.43	(0.92 %)	16.07	(34.33 %)	0.04	(0.10 %)	0.20	(0.44 %)
CO_2	636.55	(9.59 %)	238.74	(3.60 %)	25.38	(0.38 %)	62.67	(0.94 %)
CO_2-total	636.88	(8.63 %)	238.82	(3.24 %)	25.38	(0.34 %)	62.67	(0.85 %)
HC	0.07	(1.46 %)	3.35	(67.46 %)	0.02	(0.31 %)	0.11	(2.26 %)
N_2O	0.05	(17.20 %)	0.03	(9.15 %)	0	(0.00 %)	0	(0.00 %)
NH_3	0.005	(0.66 %)	0.007	(0.99 %)	0	(0.00 %)	0	(0.00 %)
NMVOC	0.05	(0.59 %)	7.26	(85.44 %)	0	(0.00 %)	0	(0.00 %)
NO_2	0.40	(12.87 %)	0.26	(8.22 %)	0	(0.00 %)	0	(0.00 %)
NO_x	1.79	(7.02 %)	2.25	(8.83 %)	0.38	(1.48 %)	1.15	(4.49 %)
OC	0.01	(4.01 %)	0.14	(42.81 %)	0.002	(0.54 %)	0.05	(14.35 %)
PM_{10}	0.03	(2.78 %)	0.21	(22.63 %)	0.005	(0.52 %)	0.13	(13.89 %)
PM_{10}-brakewear	0.0006	(0.27 %)	0.004	(1.96 %)	0.0001	(0.04 %)	0.003	(1.19 %)
PM_{10}-tirewear	0.0006	(0.24 %)	0.004	(1.81 %)	0.006	(2.74 %)	0.003	(1.12 %)
$PM_{2.5}$	0.01	(1.75 %)	0.11	(14.22 %)	0.002	(0.33 %)	0.07	(8.70 %)
$PM_{2.5}$-brakewear	0.0002	(0.23 %)	0.001	(1.56 %)	3e-05	(0.04 %)	0.0008	(0.95 %)
$PM_{2.5}$-tirewear	0.0004	(0.23 %)	0.003	(1.71 %)	0.006	(3.52 %)	0.002	(1.45 %)
PN	8.30×10^{24}	(2.05 %)	2.97×10^{24}	(0.73 %)	0	(0.00 %)	0	(0.00 %)
PN-brakewear	9.39×10^{22}	(1.13 %)	1.60×10^{24}	(19.31 %)	0	(0.00 %)	0	(0.00 %)
SO_2	0.002	(0.25 %)	0.004	(0.41 %)	0.0002	(0.02 %)	0.0004	(0.04 %)

Table S4: Globally aggregated emissions of the land transport sector. Units are Tg(species), Tg(NO_2) for NO_x and particles for PN. The acronyms LCV and HFT indicate light commercial vehicles and heavy freight trucks, respectively. The percentage figures in brackets are the share by each subsectors to the total land transport emissions.

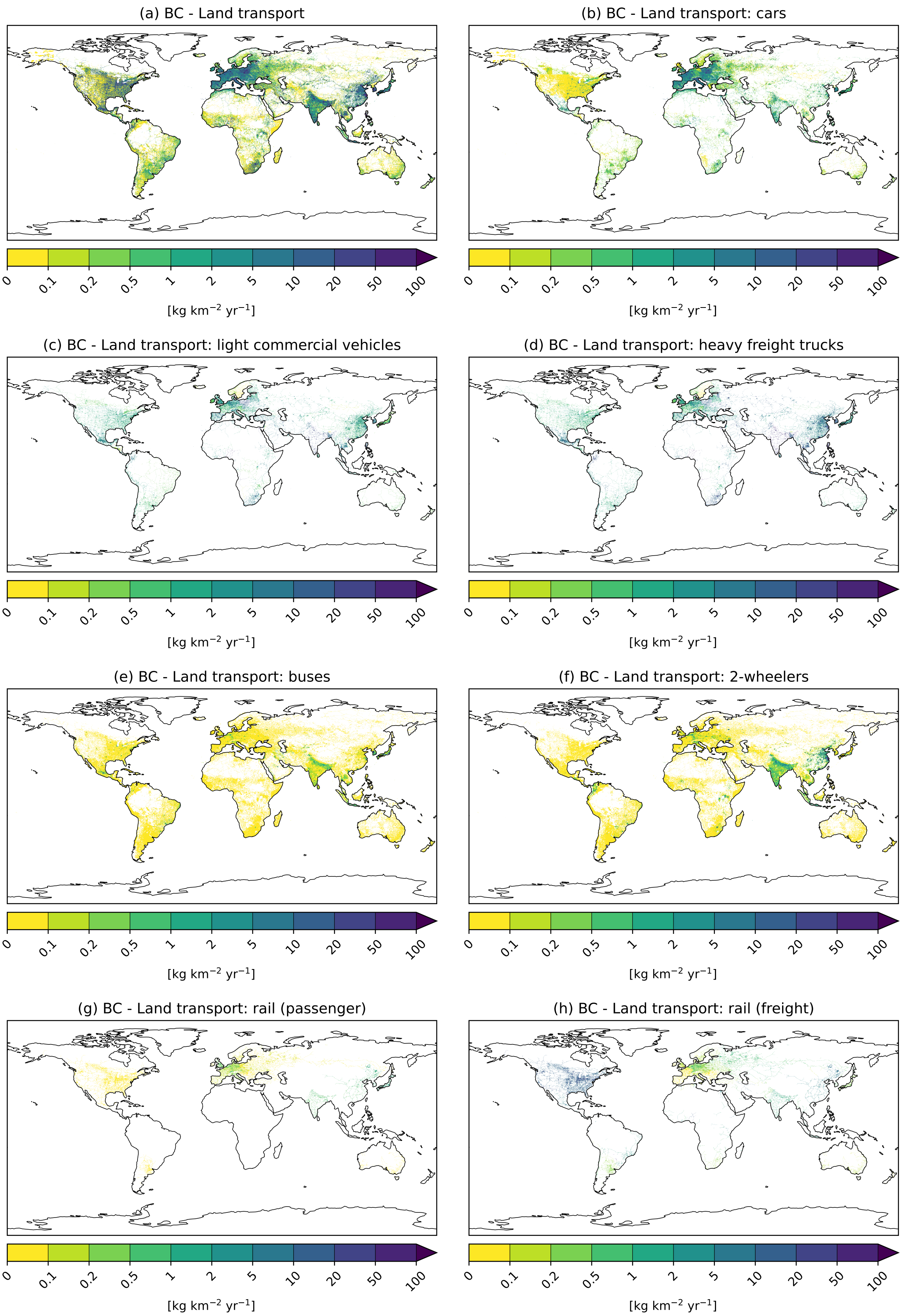


Figure S3: BC emissions from land transport.

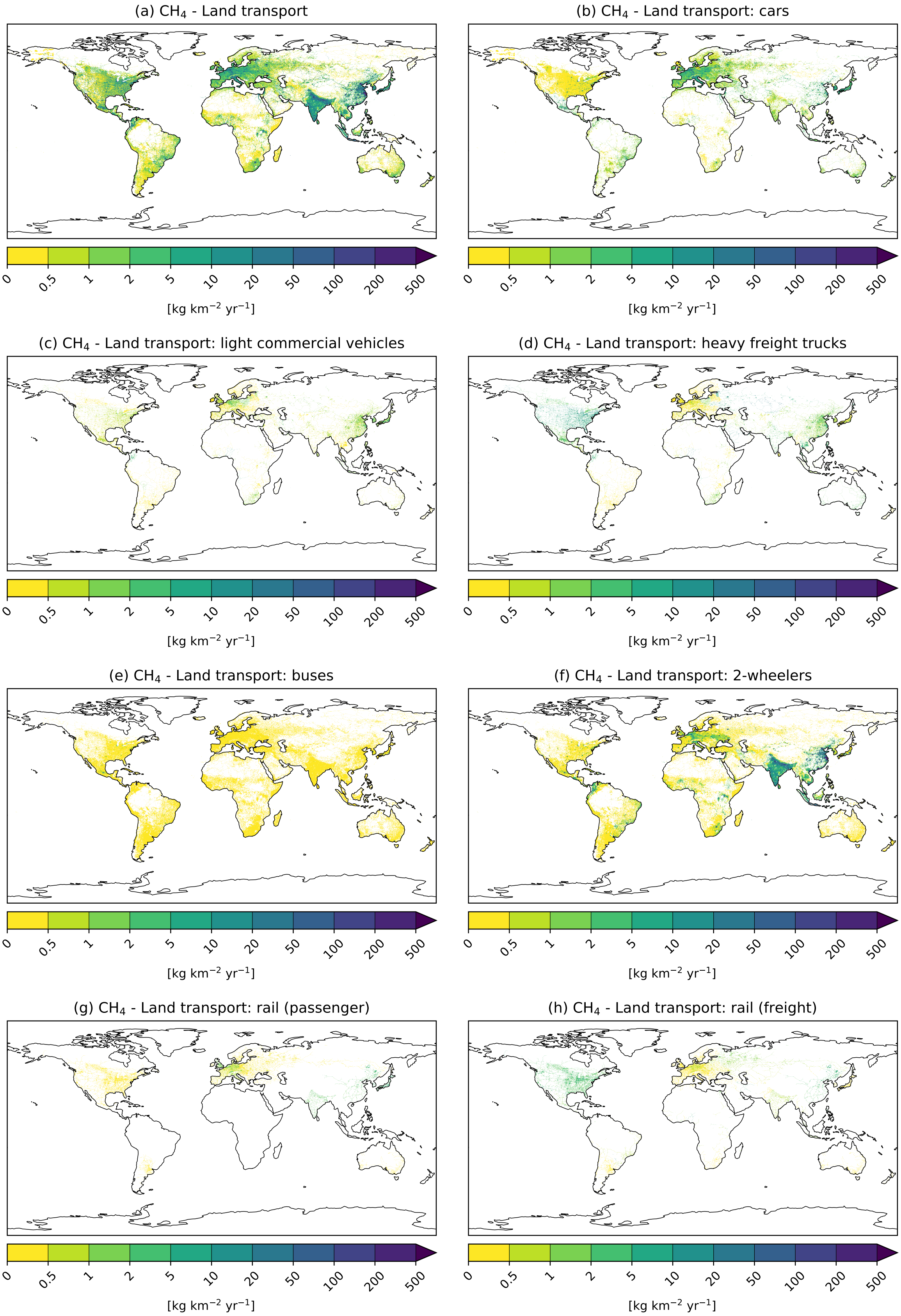


Figure S4: CH_4 emissions from land transport.

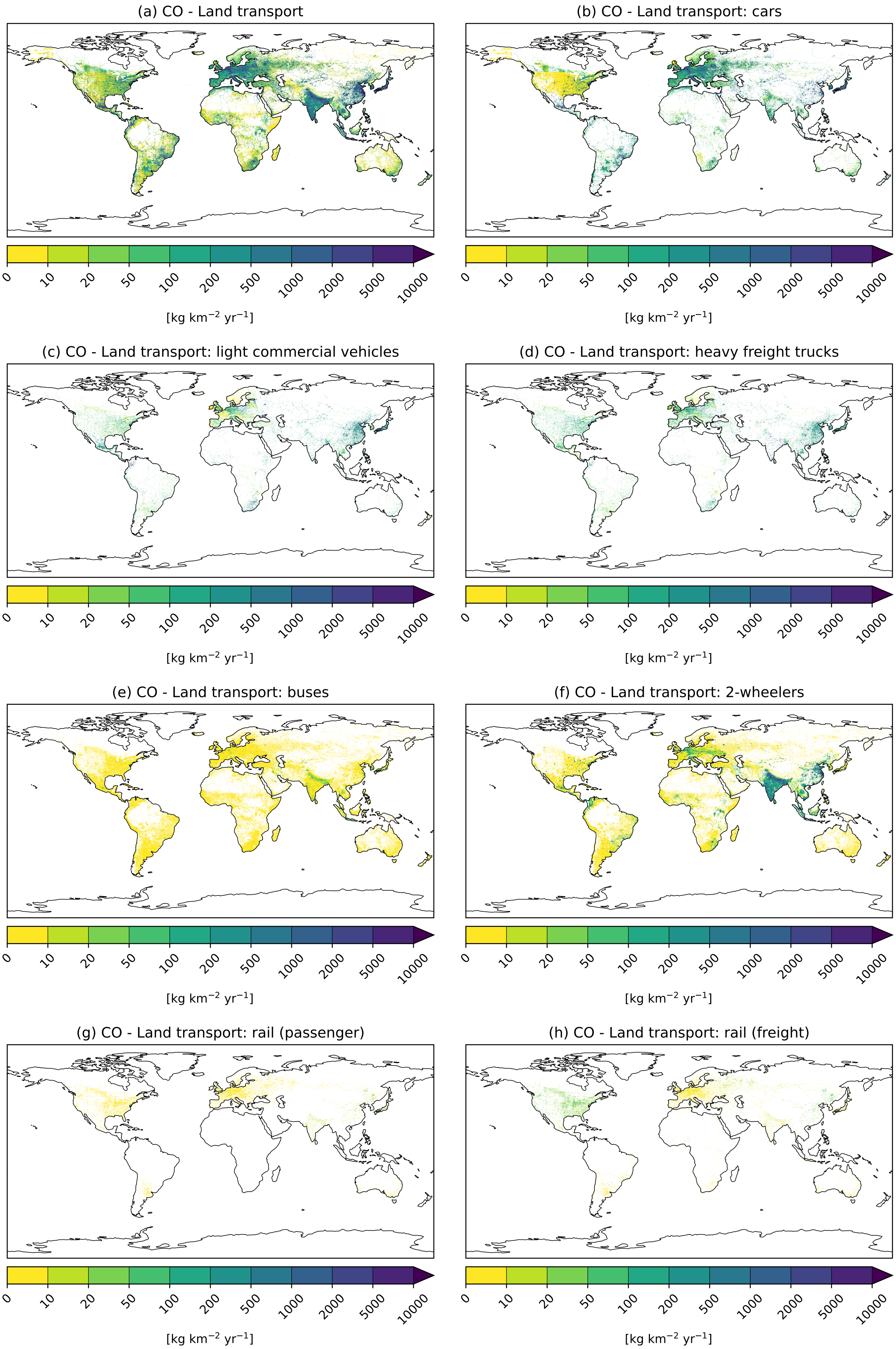


Figure S5: CO emissions from land transport.

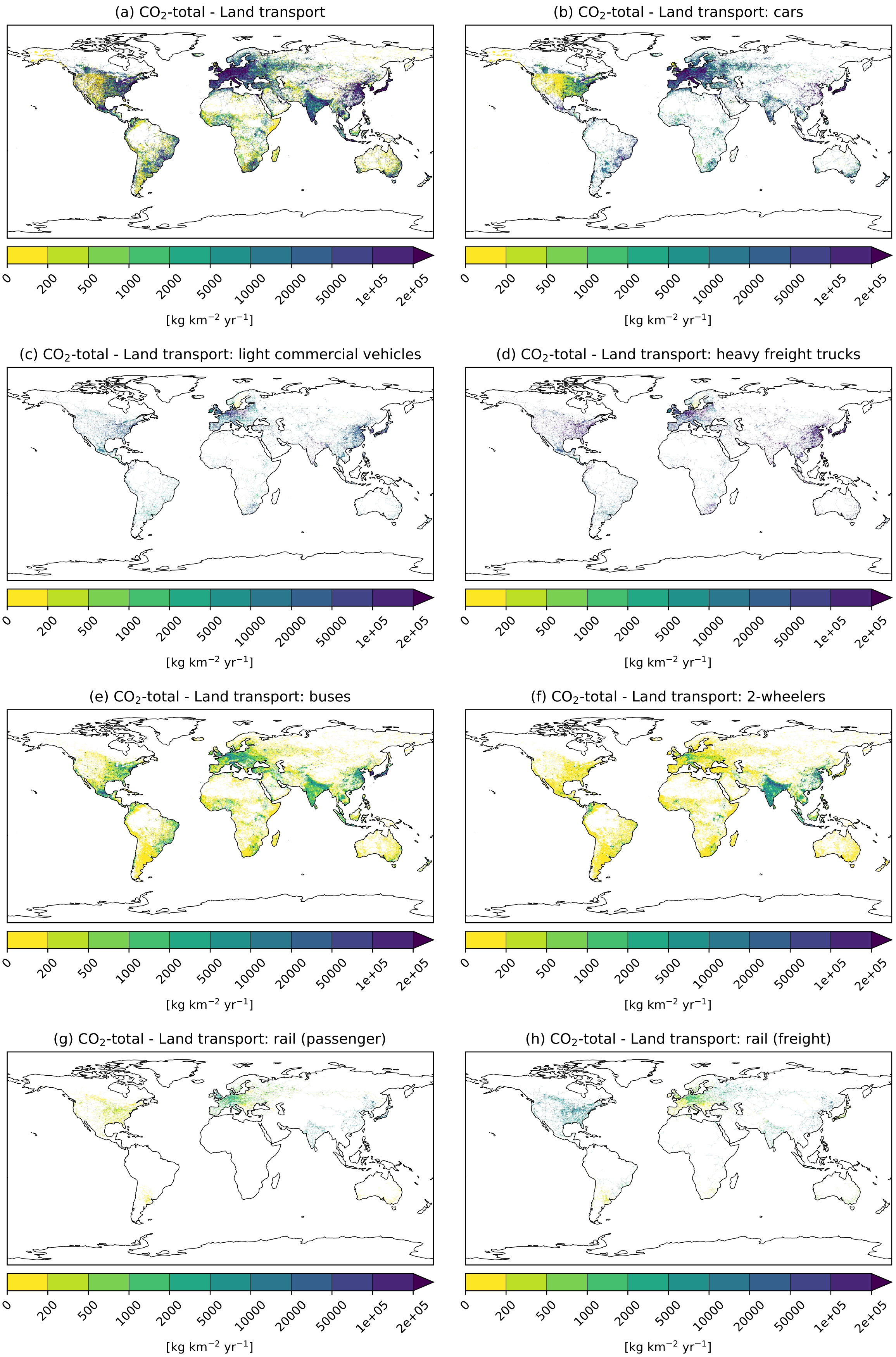


Figure S6: CO_2-total emissions from land transport, including the share of biofuels.

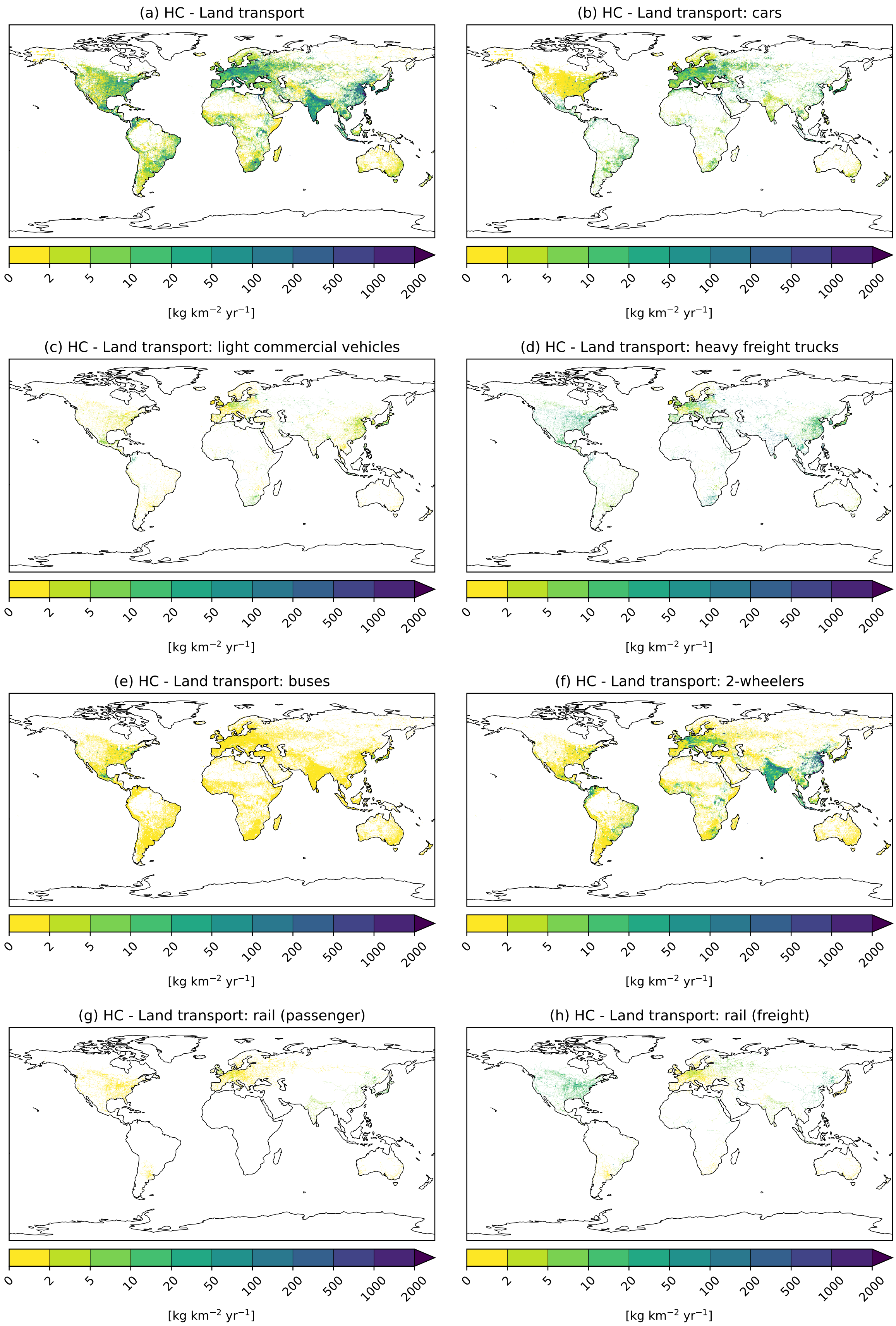


Figure S7: HC emissions from land transport.

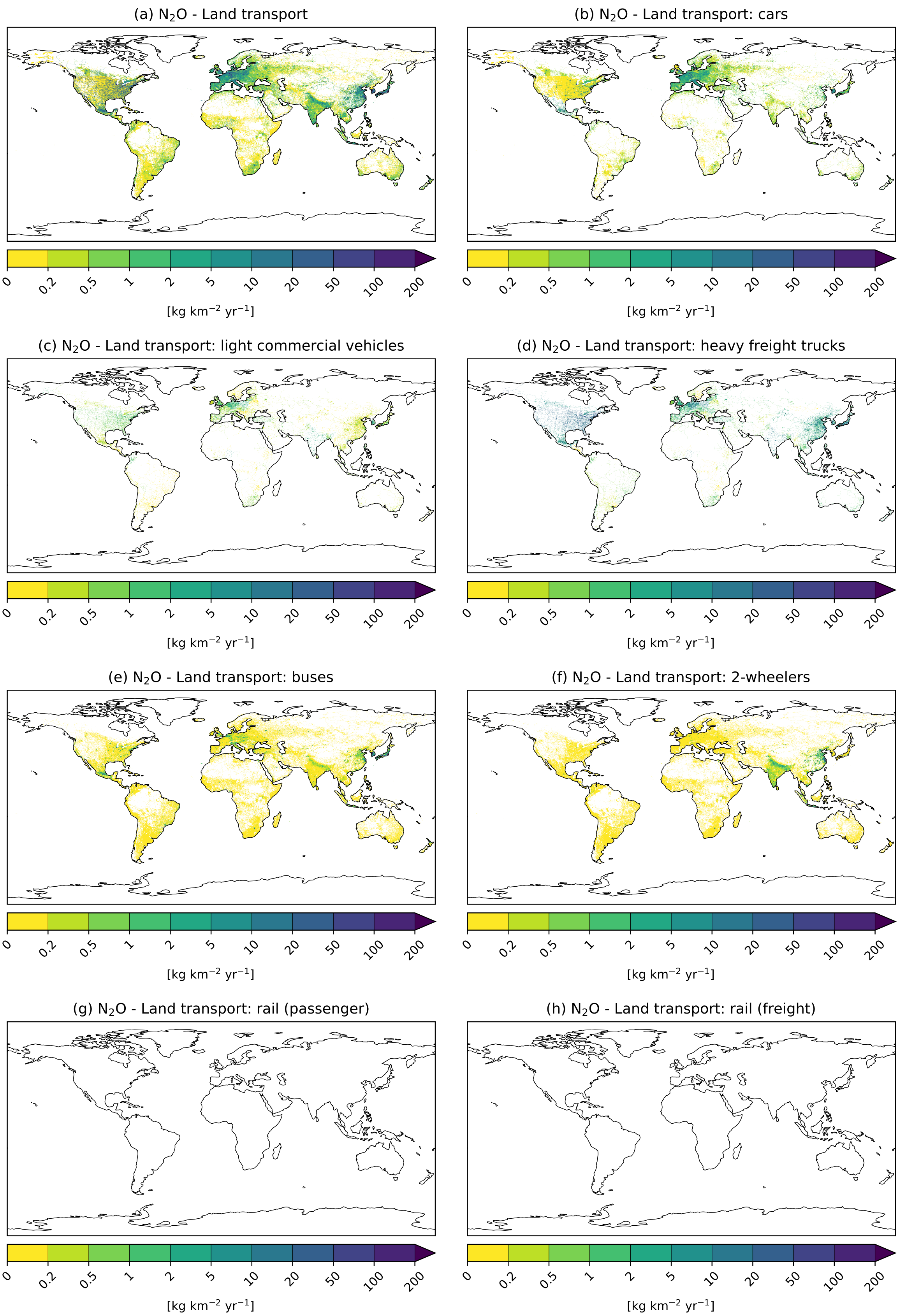


Figure S8: N_2O emissions from land transport.

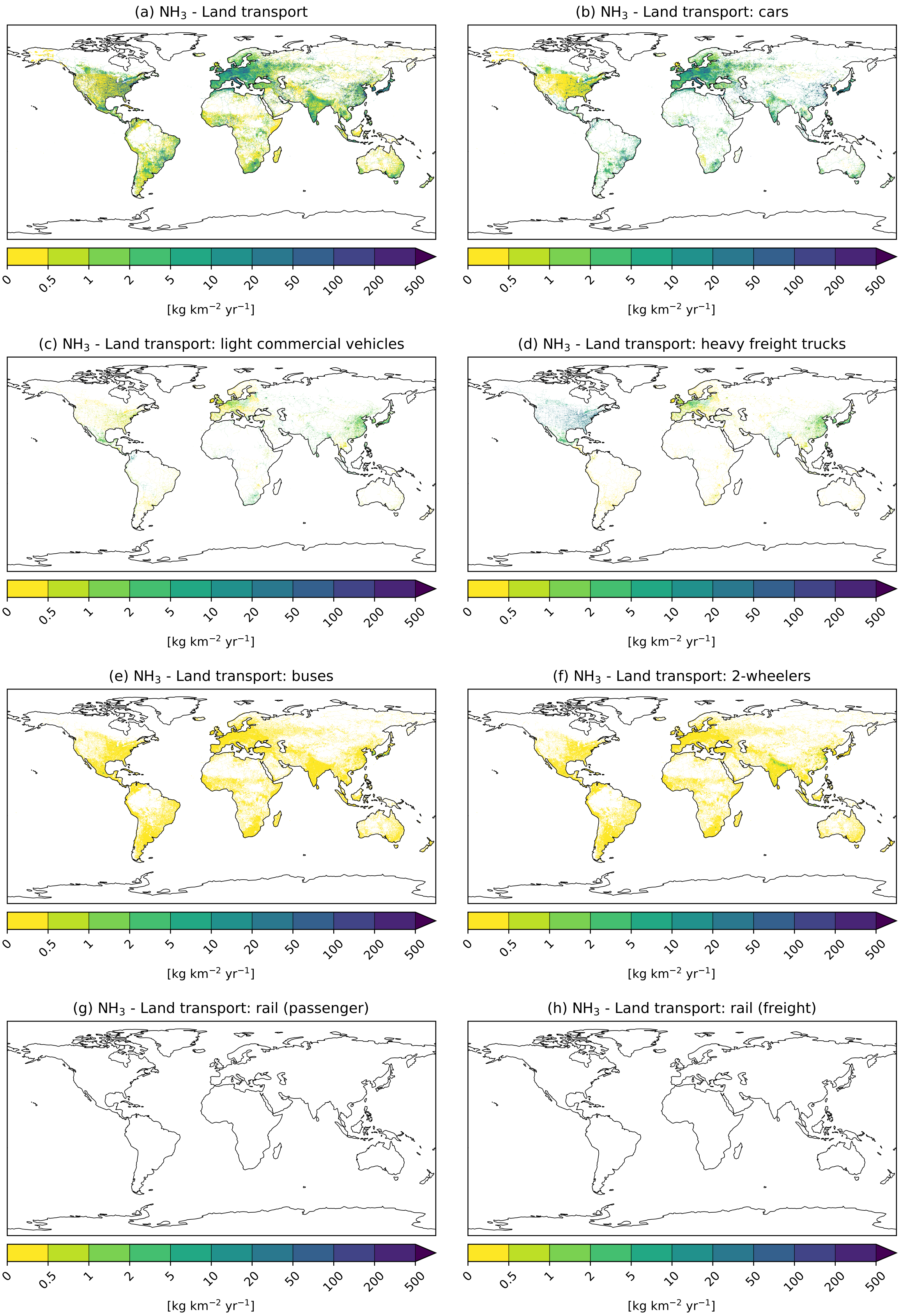


Figure S9: NH_3 emissions from land transport.

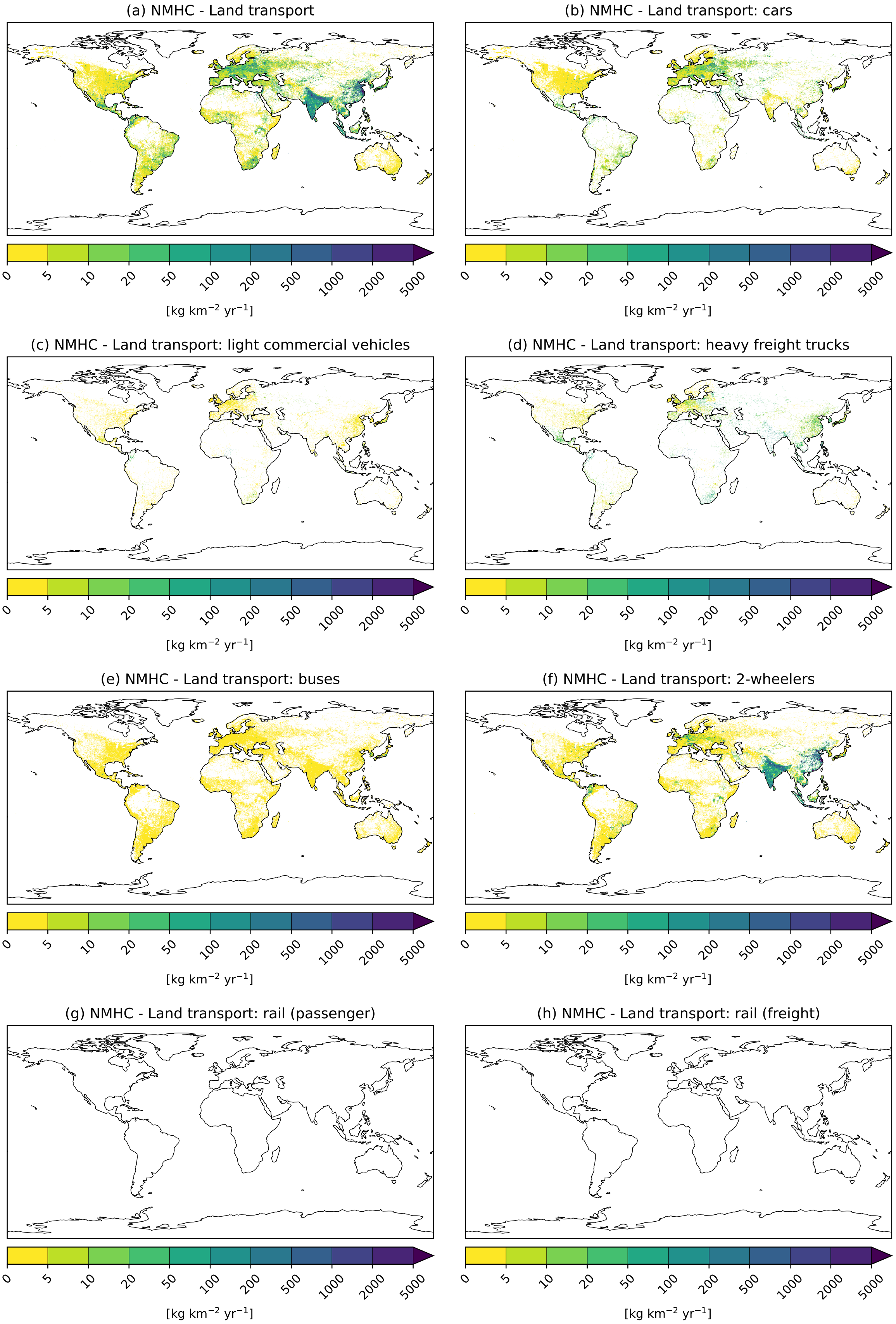


Figure S10: NMHC emissions from land transport.

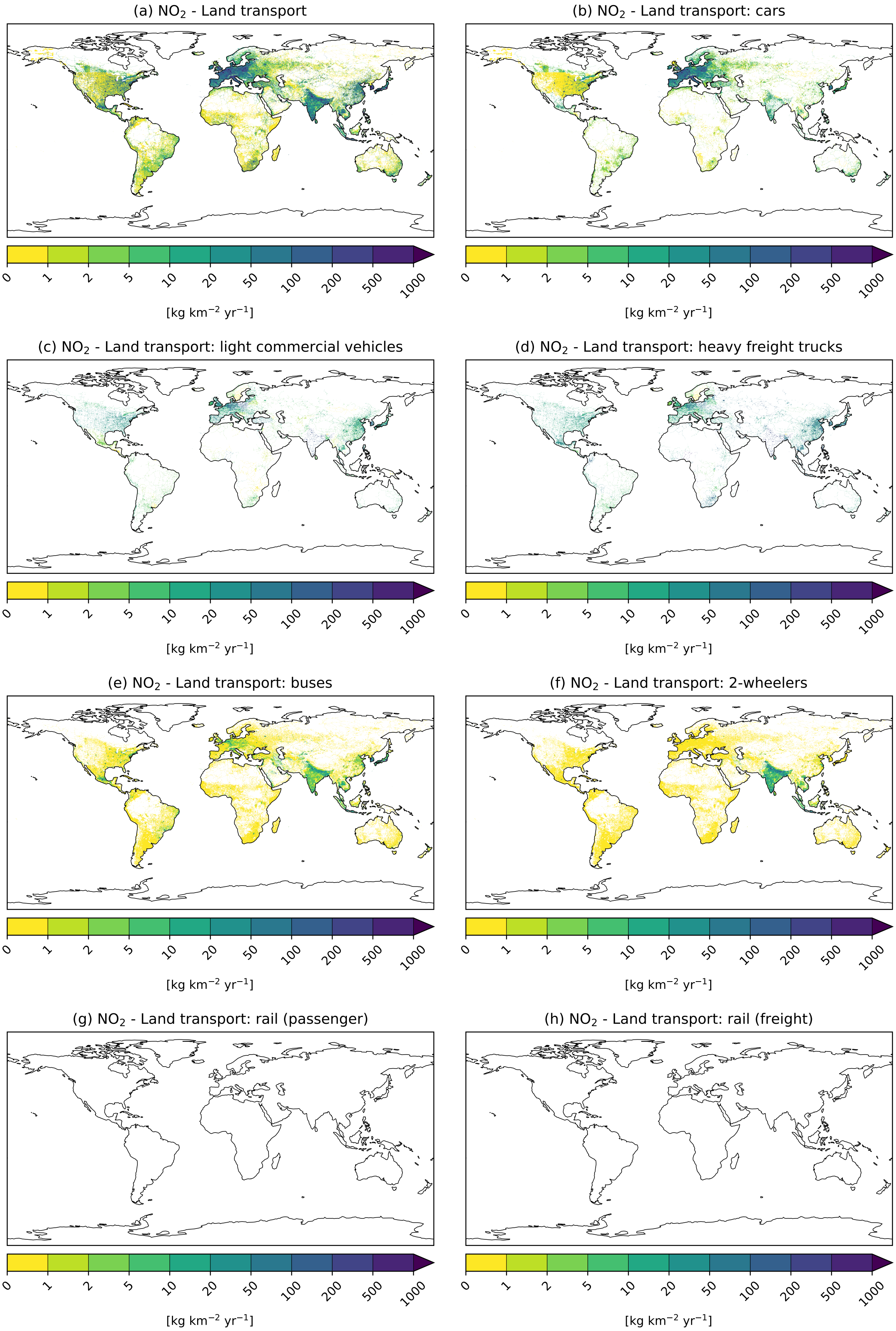


Figure S11: NO_2 emissions from land transport.

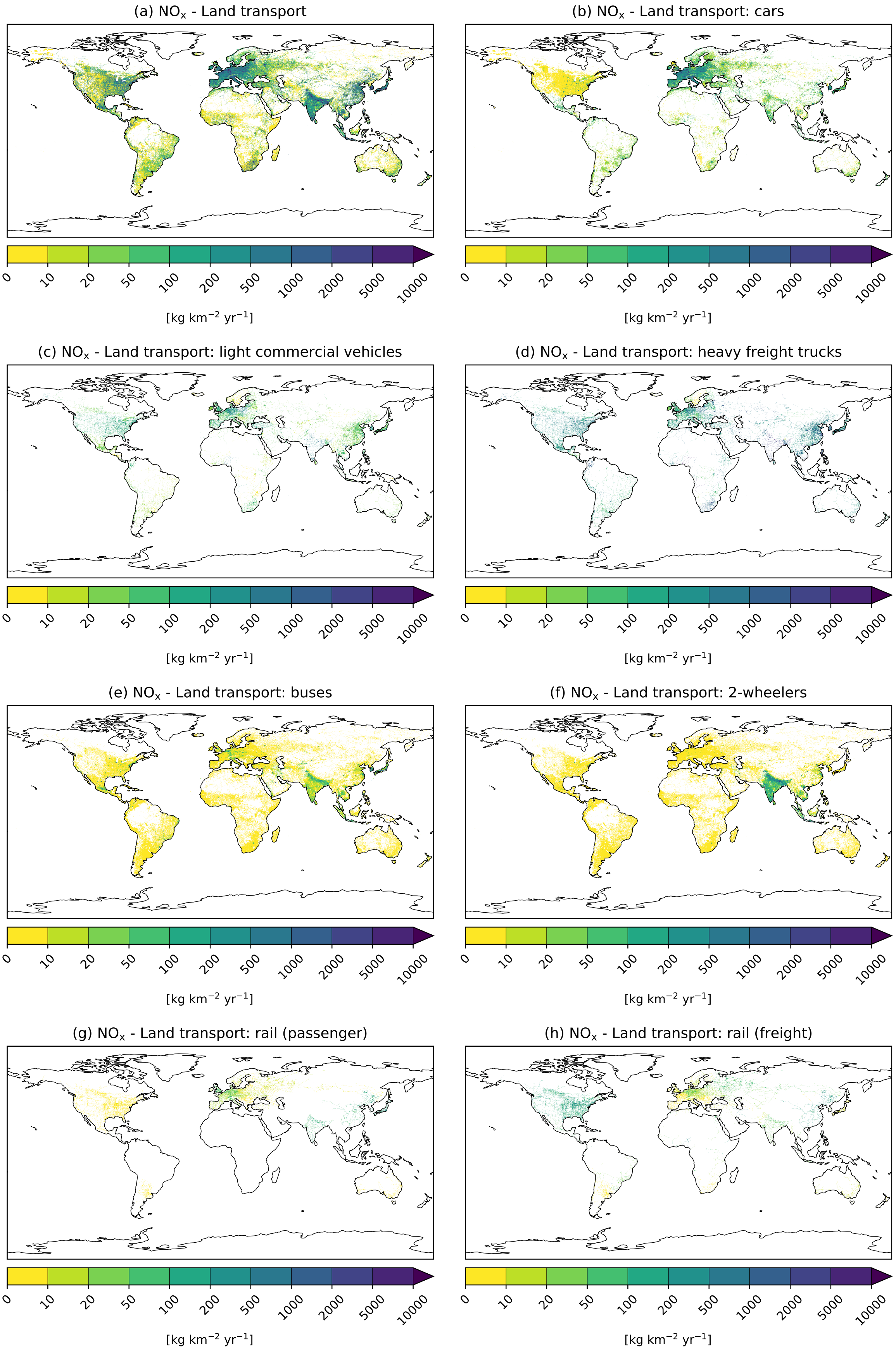


Figure S12: NO_x emissions from land transport.

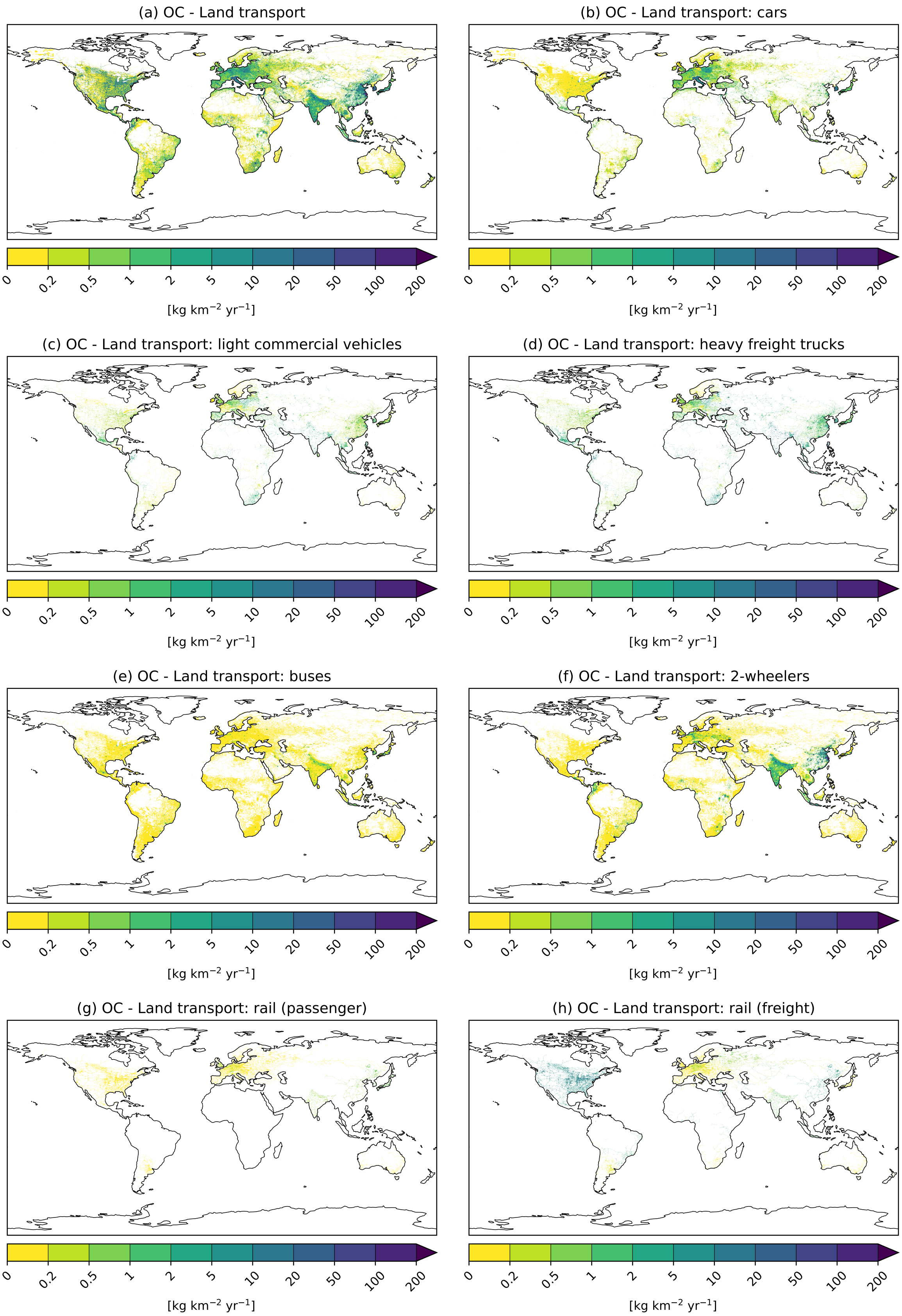


Figure S13: OC emissions from land transport.

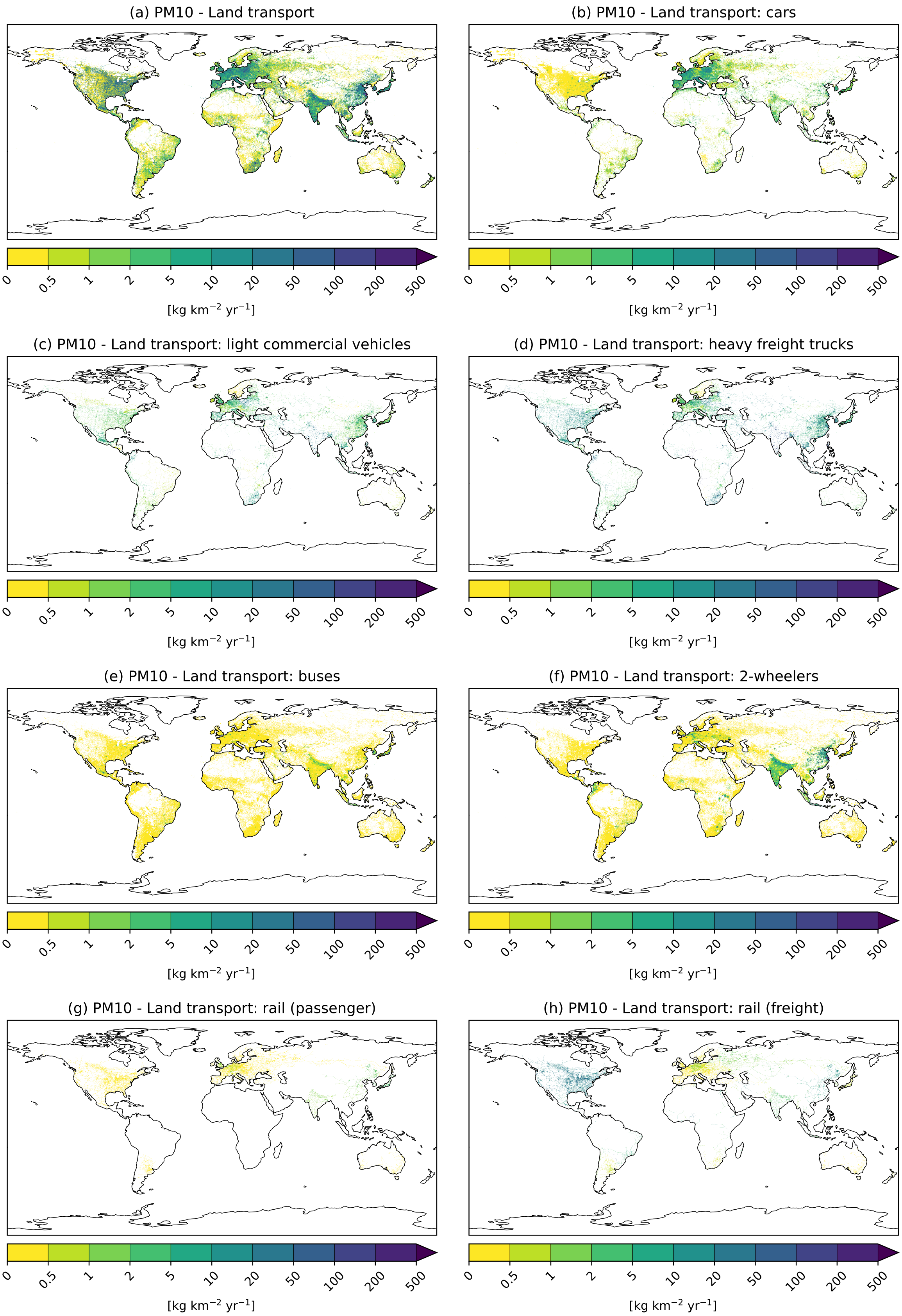


Figure S14: PM_{10} emissions from land transport.

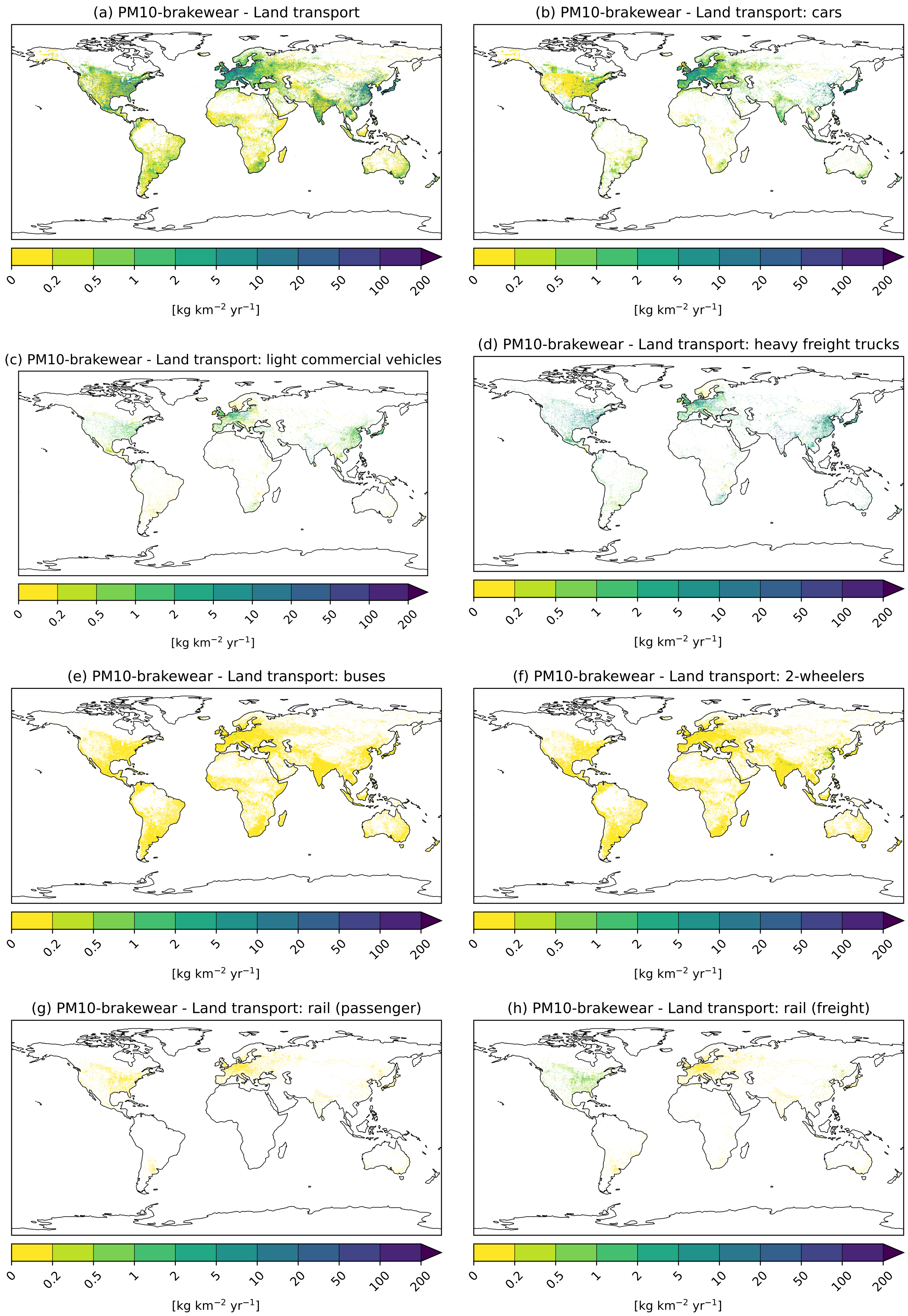


Figure S15: PM_{10} brakewear emissions from land transport.

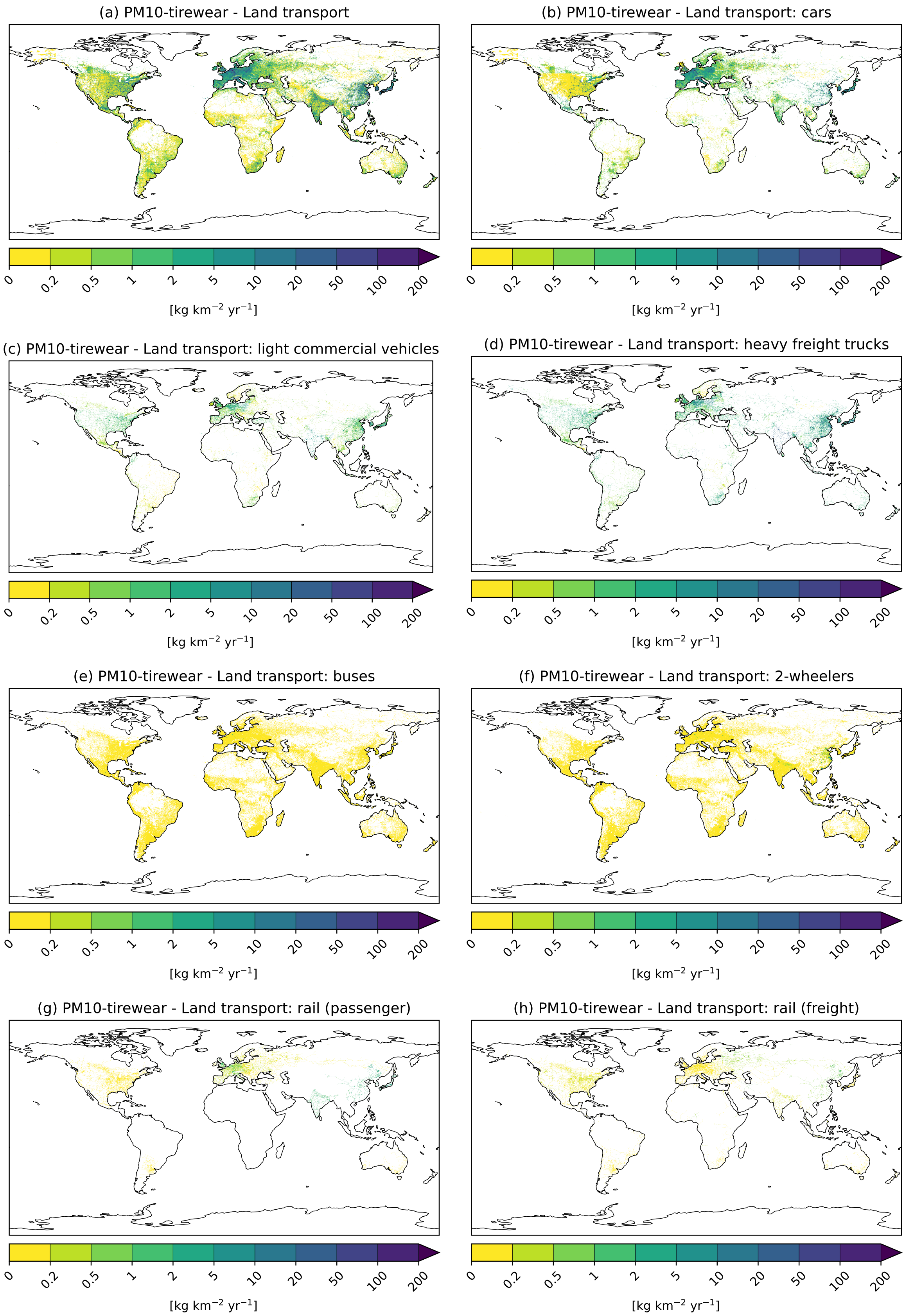


Figure S16: PM_{10} tirewear emissions from land transport.

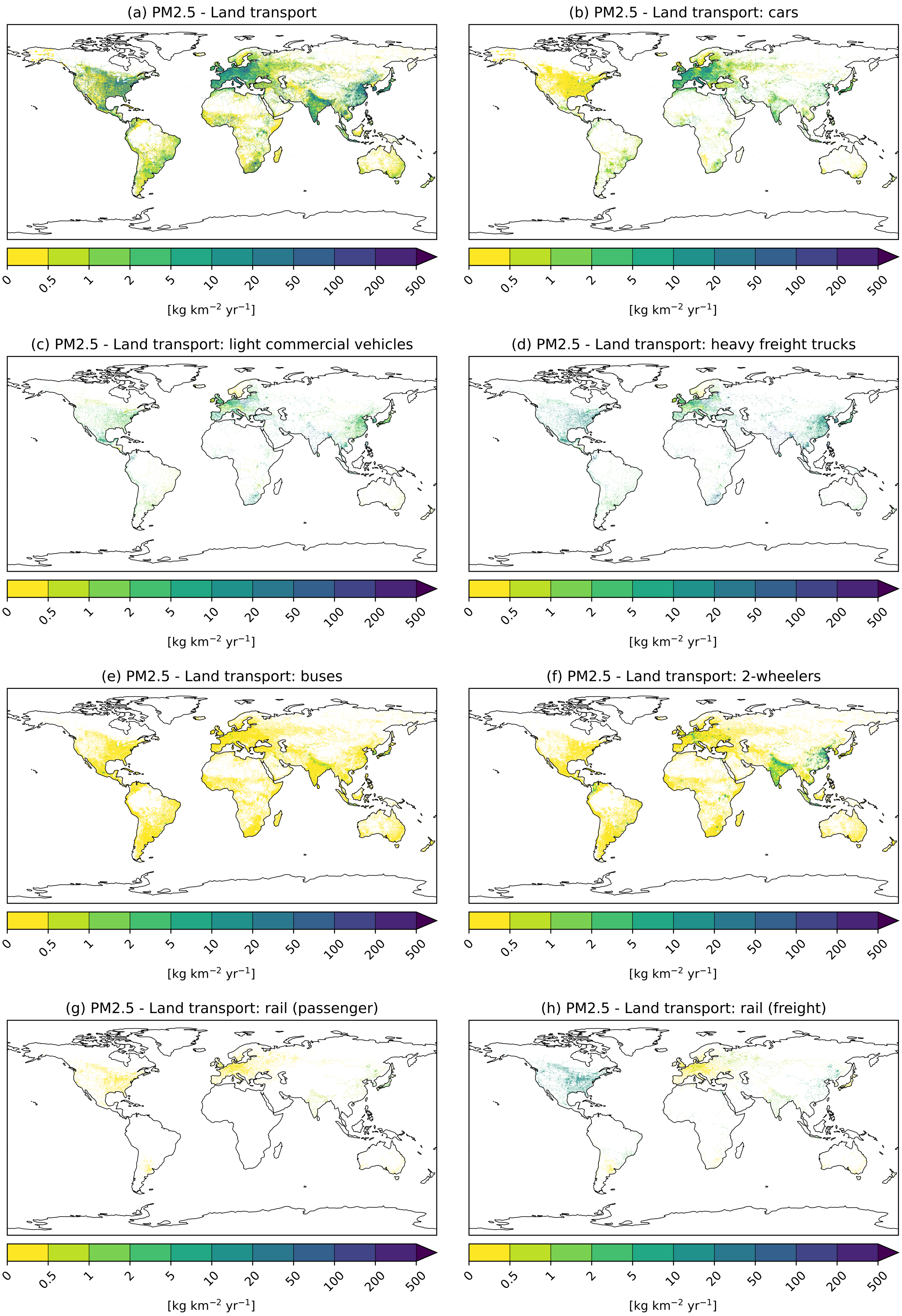


Figure S17: $PM_{2.5}$ emissions from land transport.

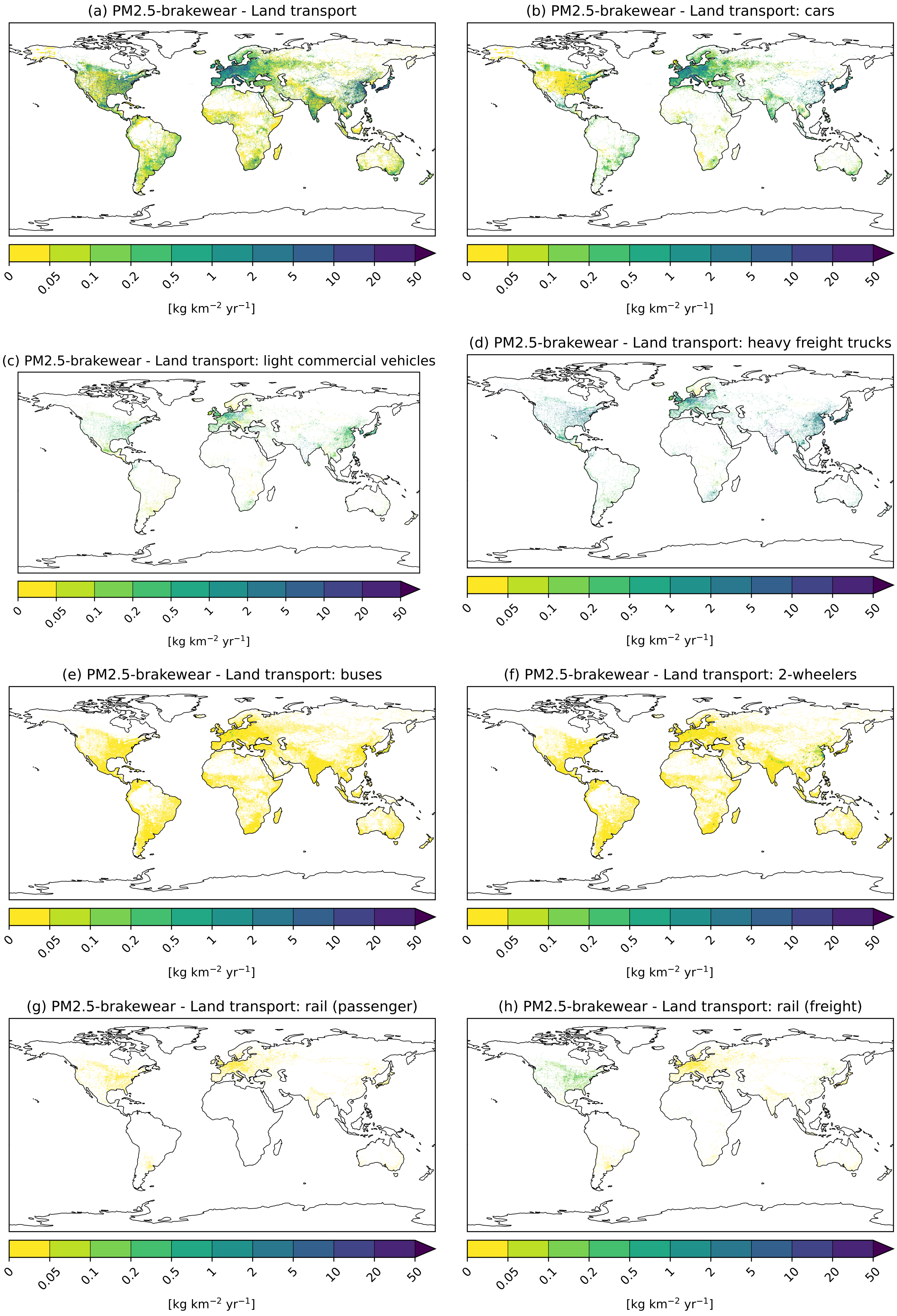


Figure S18: $PM_{2.5}$ brakewear emissions from land transport.

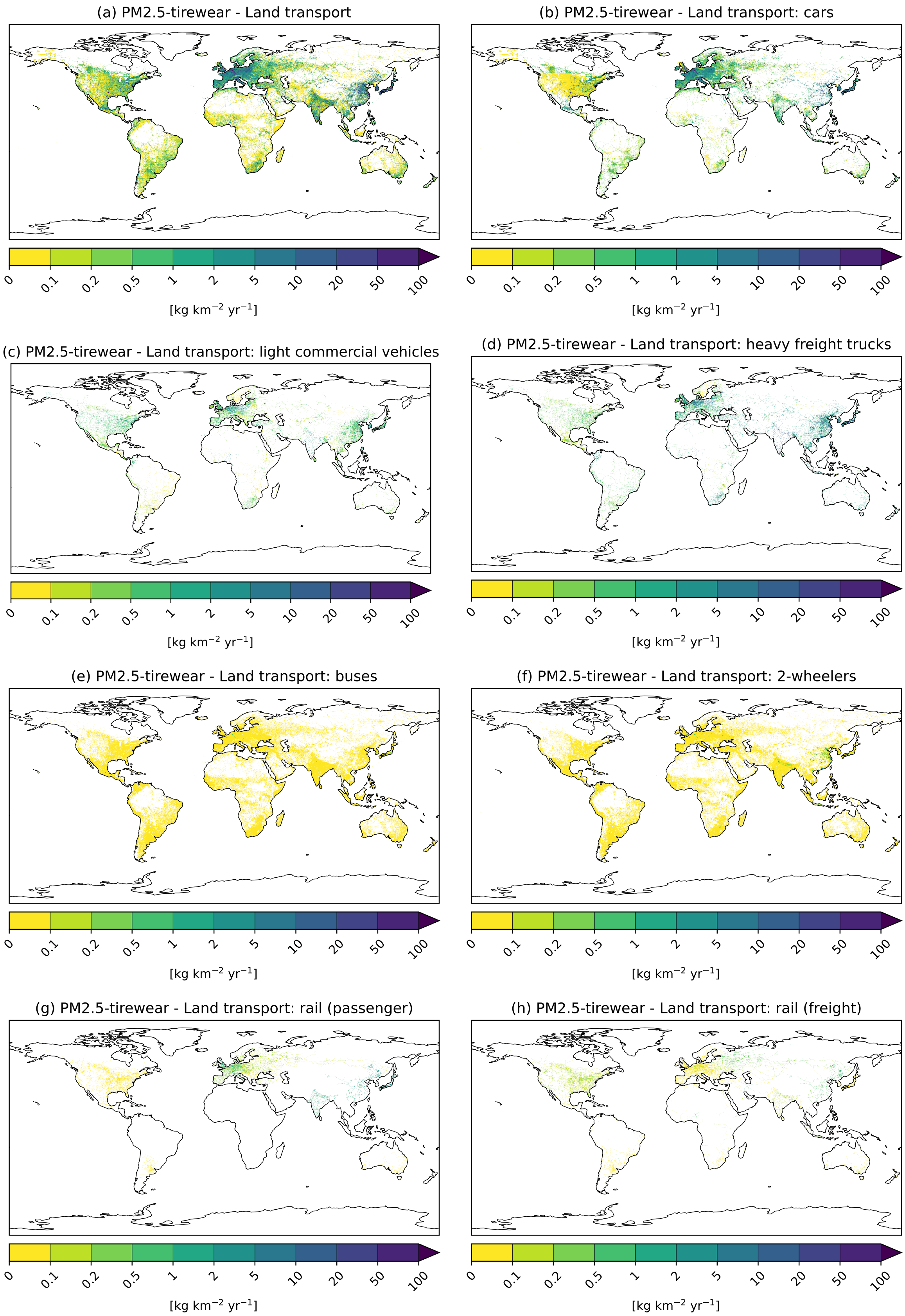


Figure S19: $PM_{2.5}$ tirewear emissions from land transport.

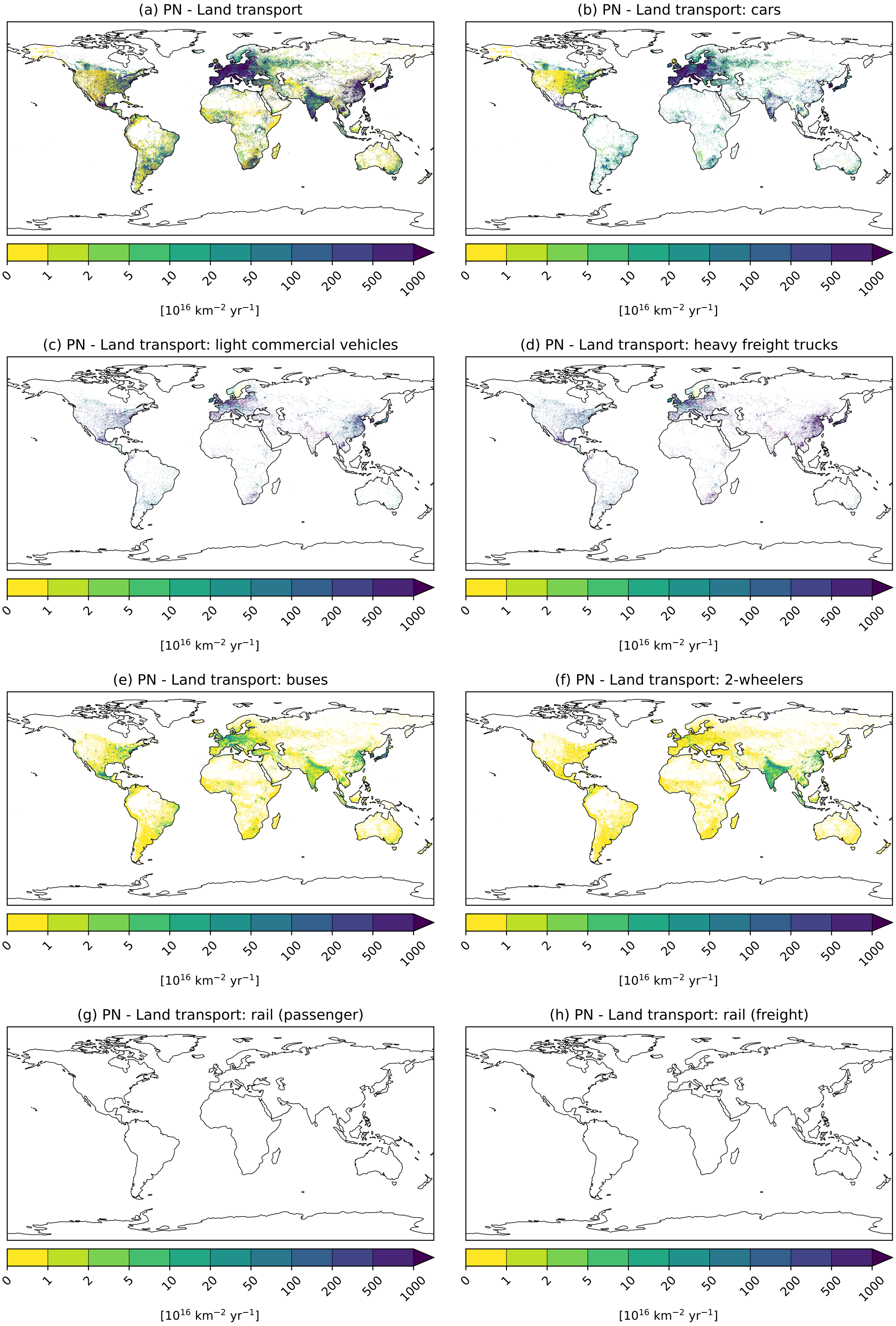


Figure S20: PN emissions from land transport.

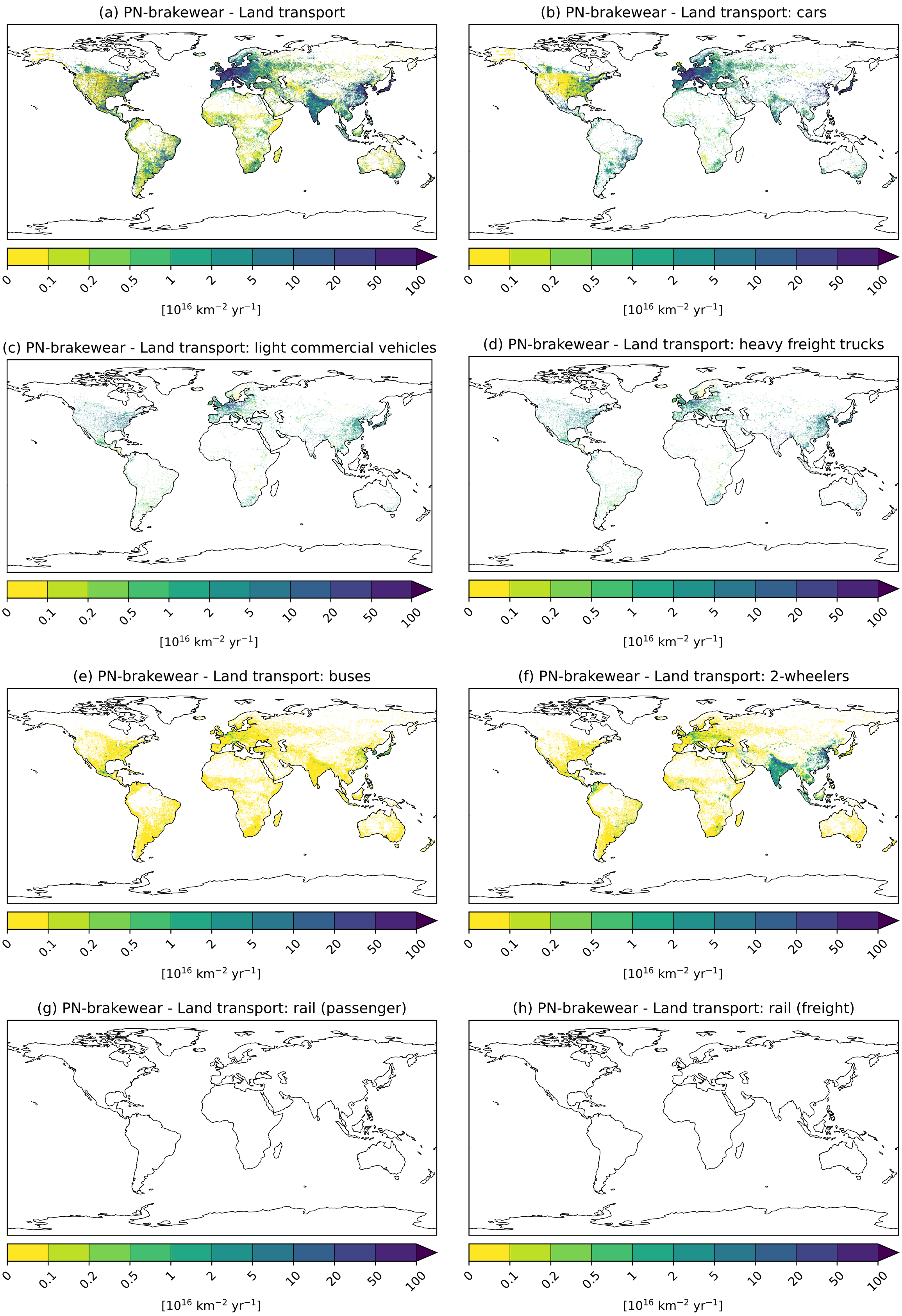


Figure S21: PN brakewear emissions from land transport.

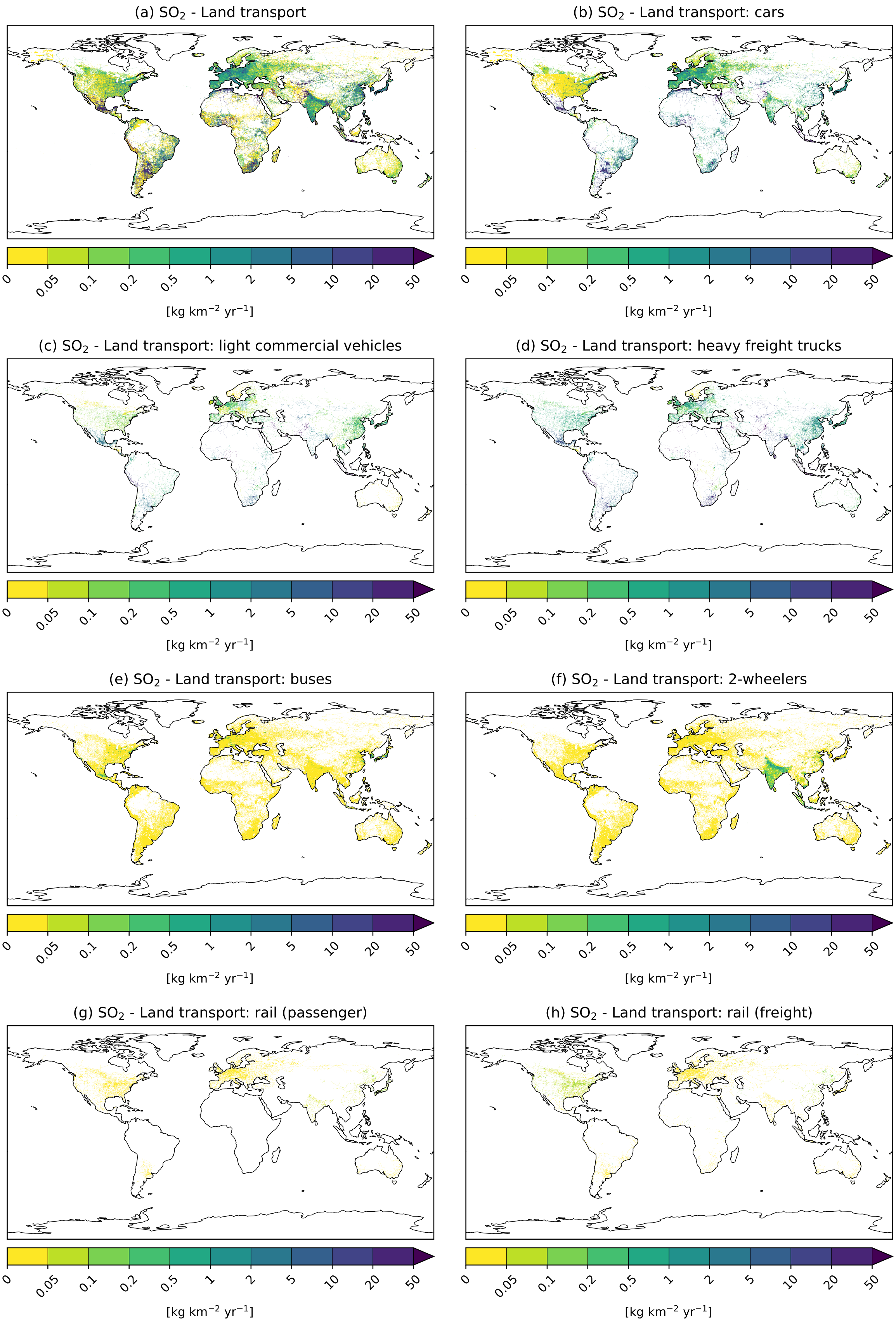


Figure S22: SO_2 emissions from land transport.

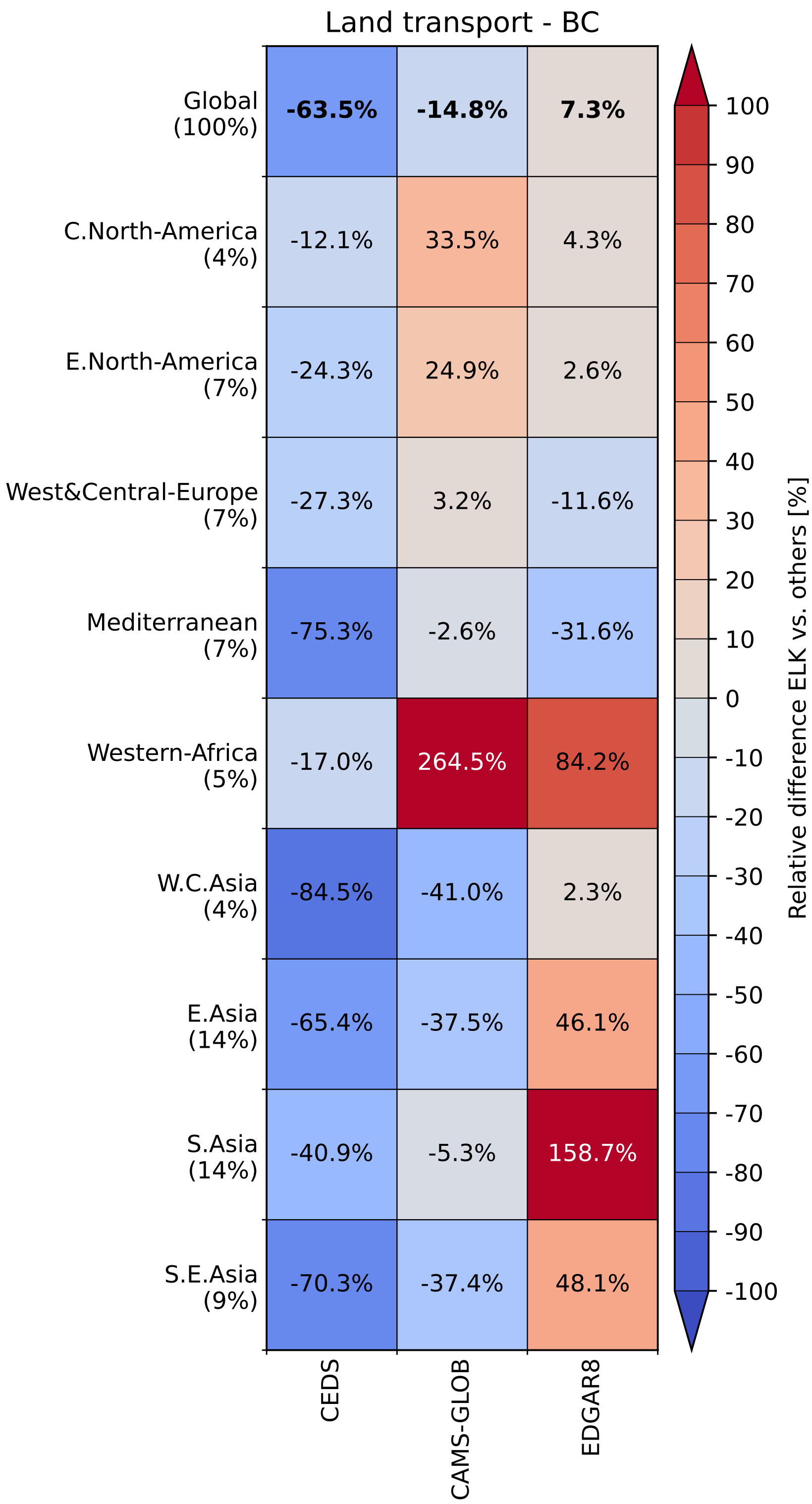


Figure S23: Relative difference of aggregated land transport emissions of BC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

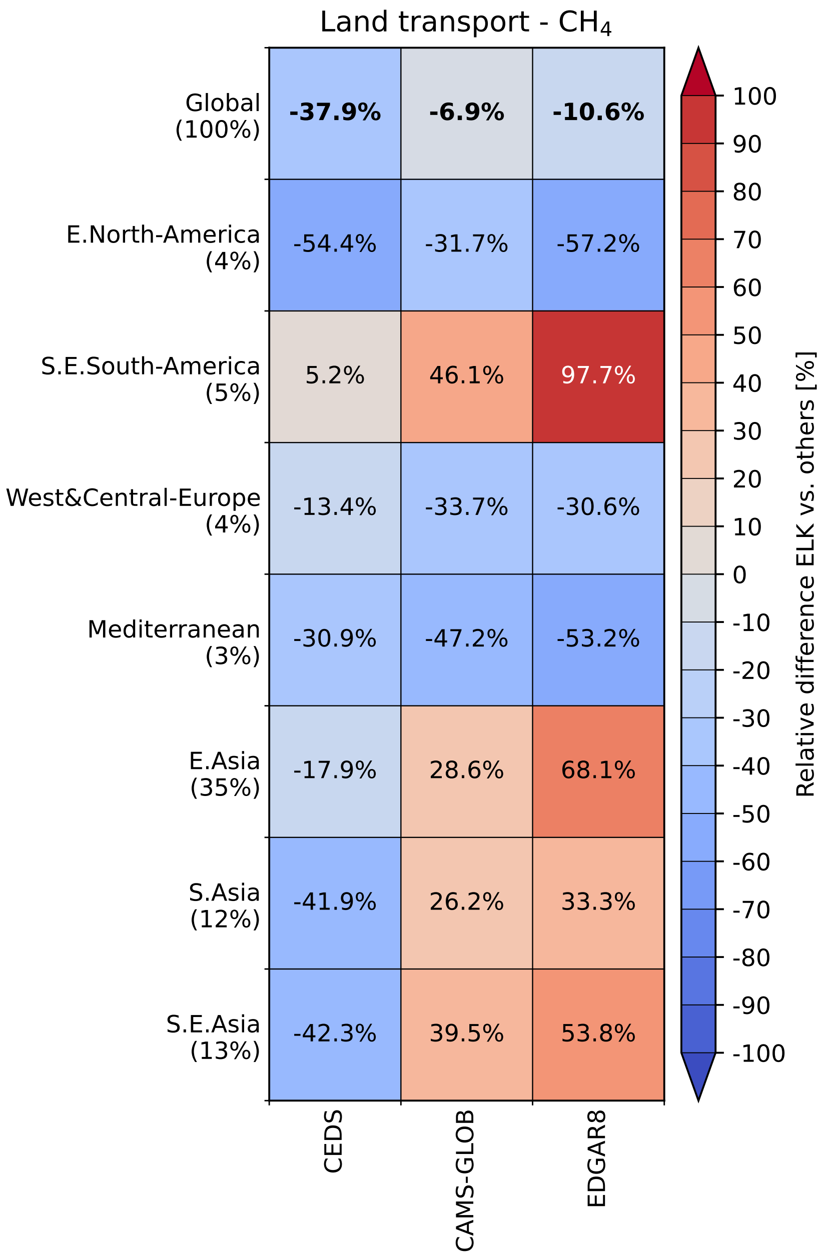


Figure S24: Relative difference of aggregated land transport emissions of CH_4 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

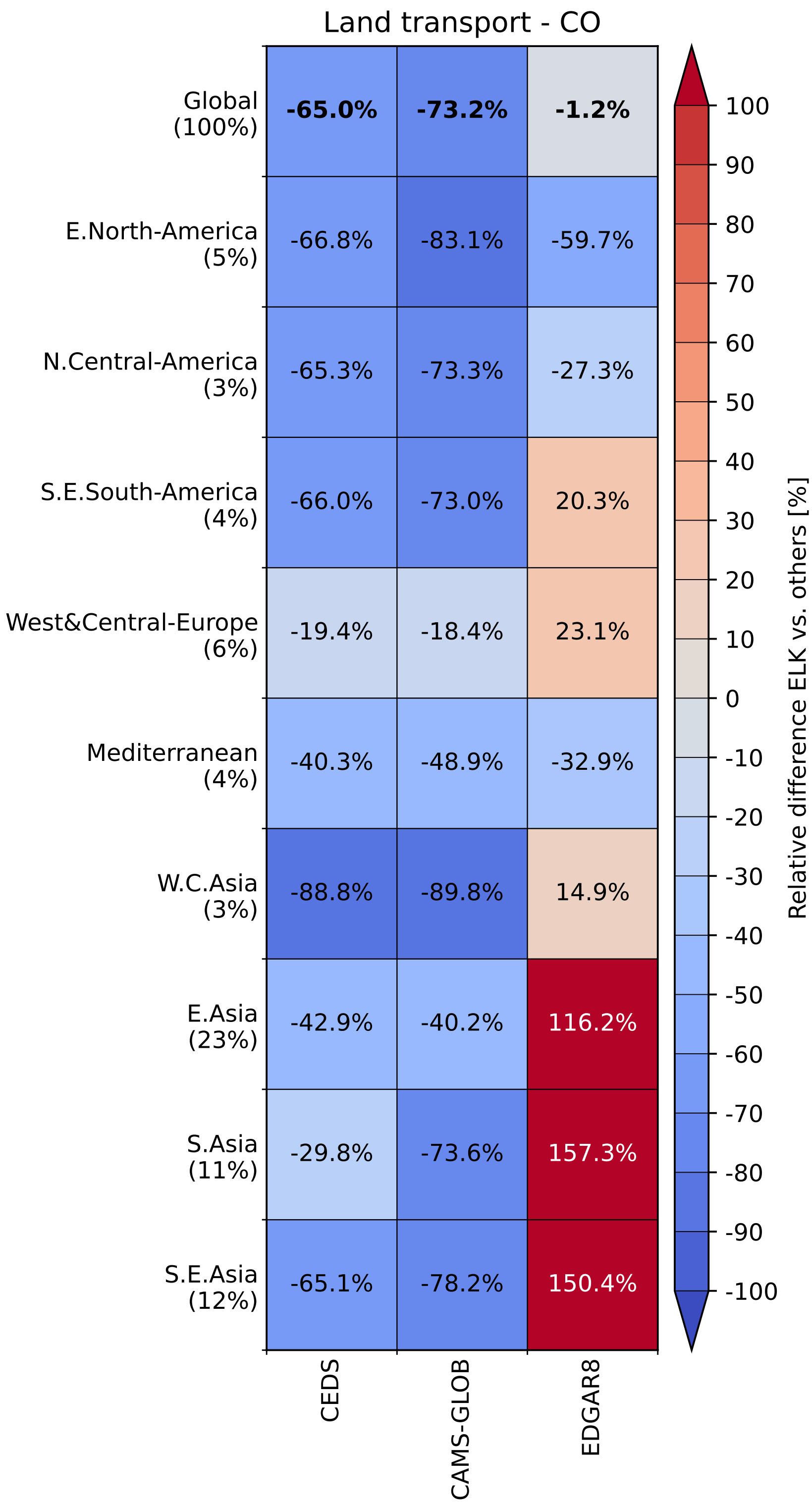


Figure S25: Relative difference of aggregated land transport emissions of CO between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

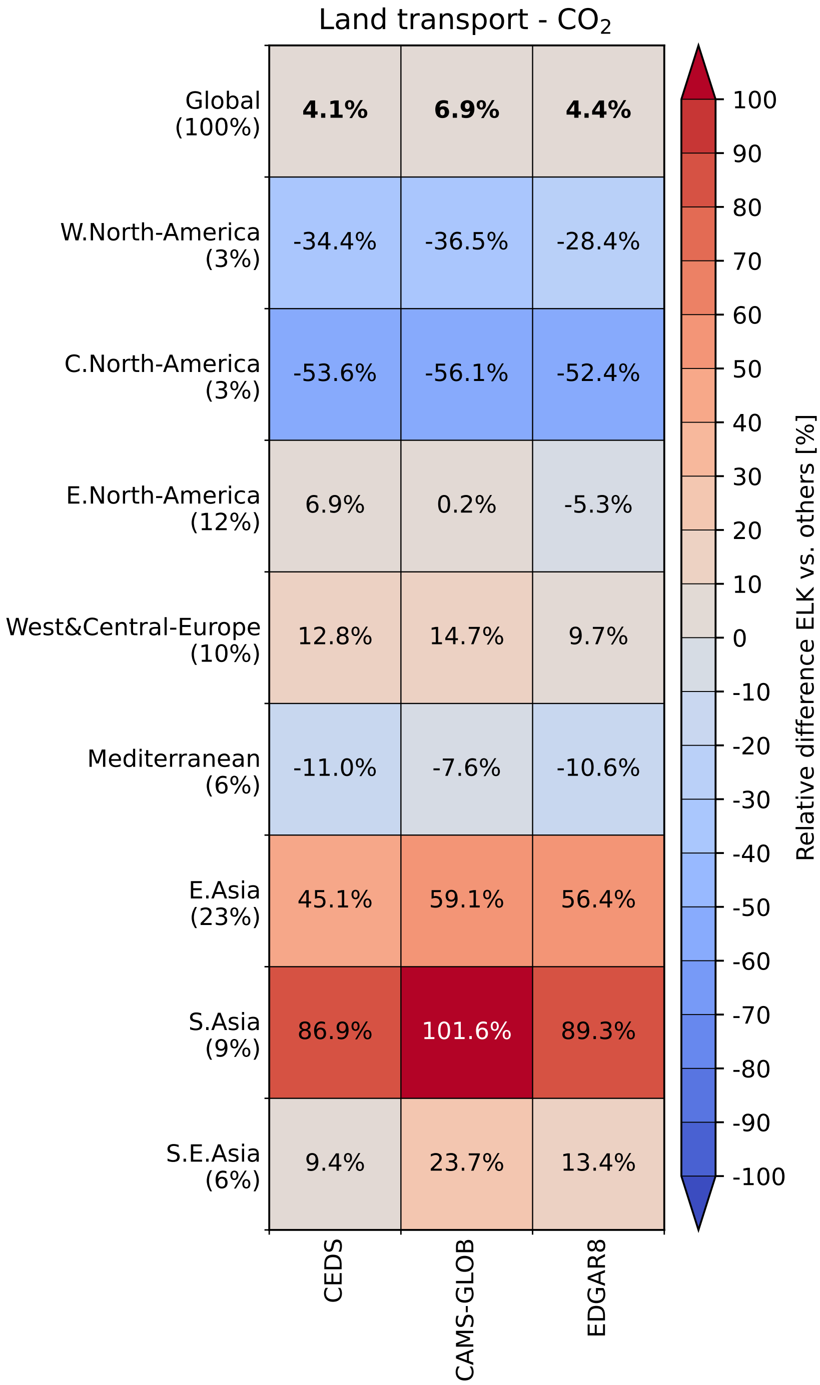


Figure S26: Relative difference of aggregated land transport emissions of CO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

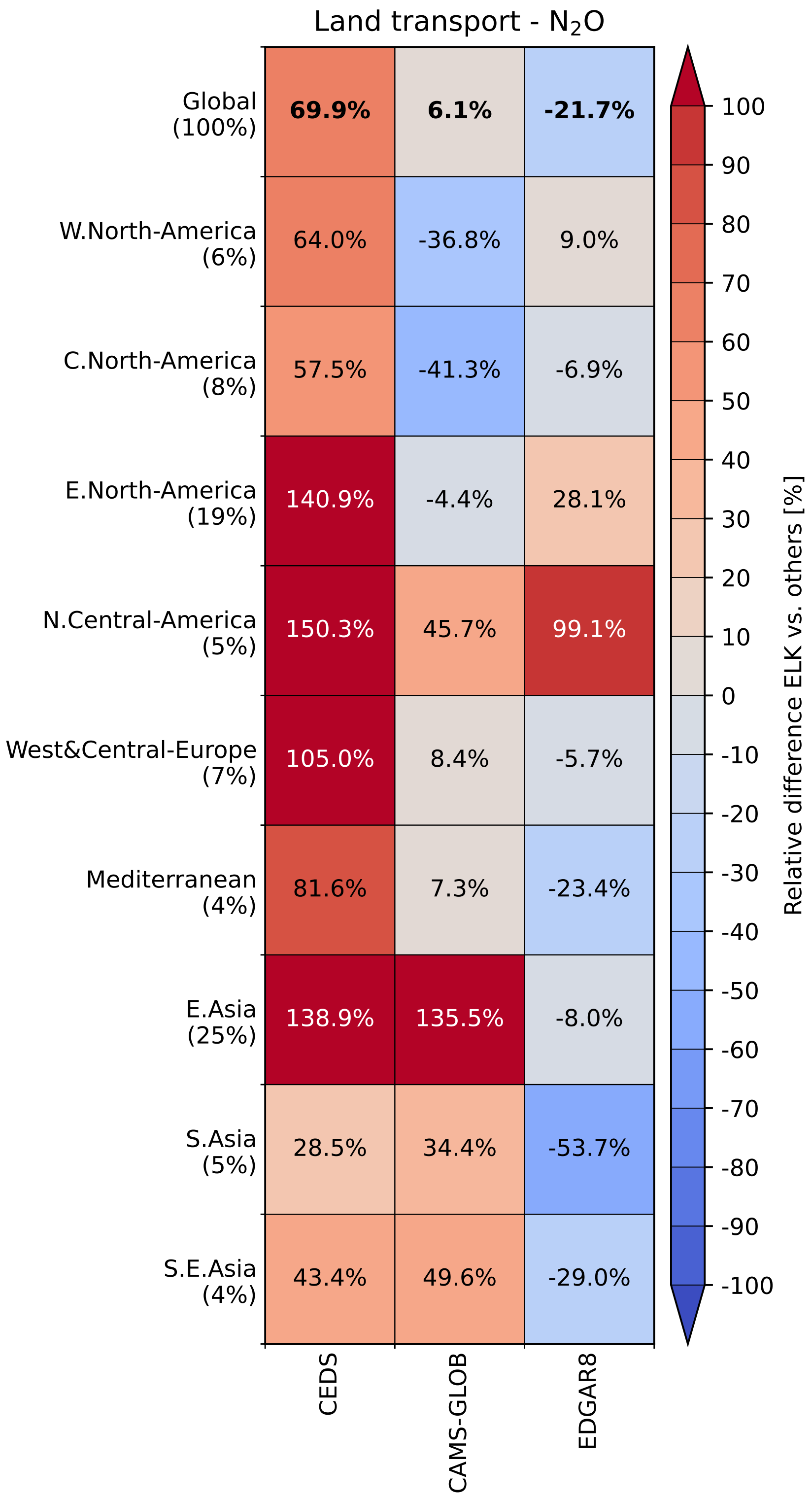


Figure S27: Relative difference of aggregated land transport emissions of N_2O between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

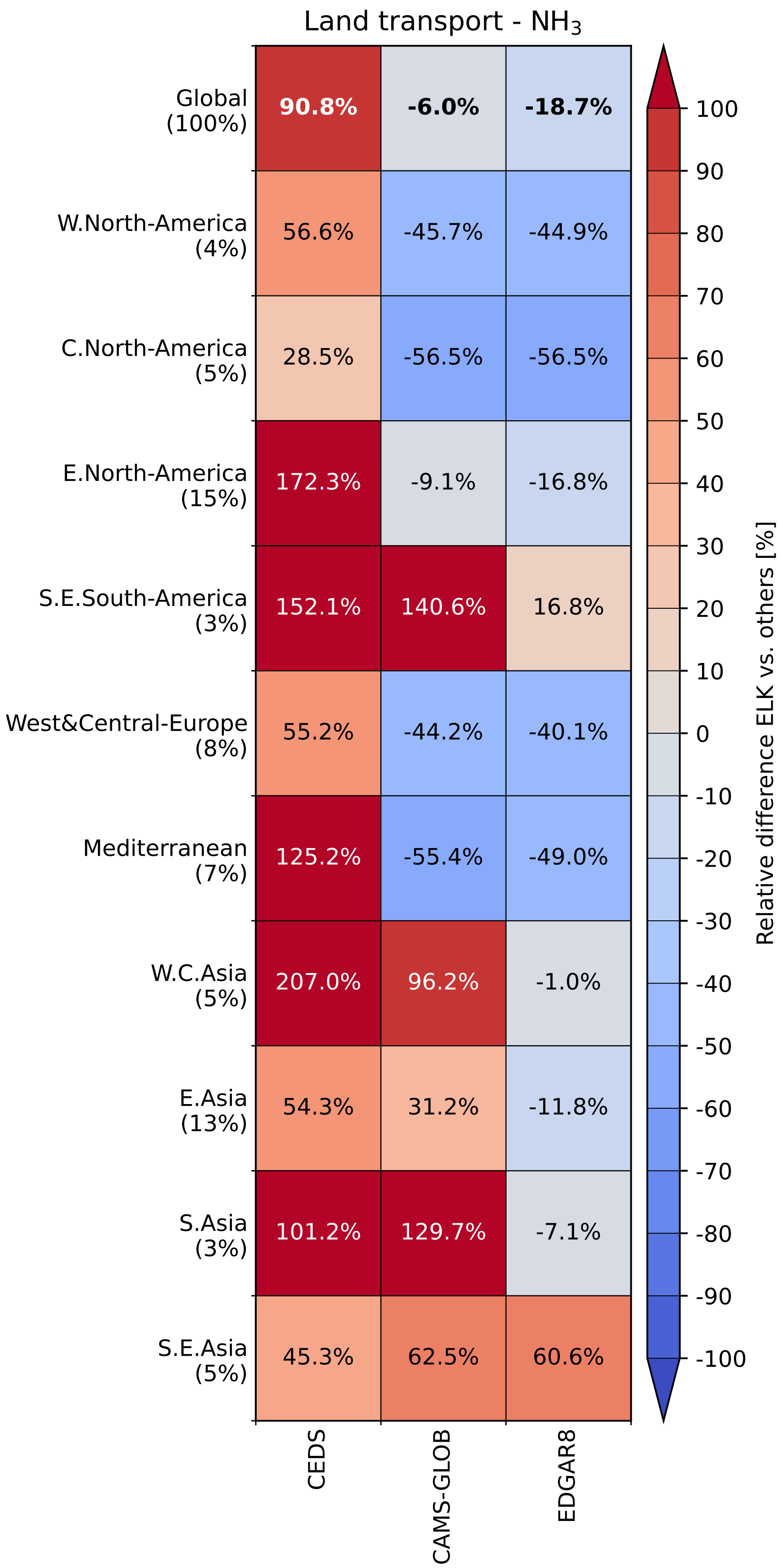


Figure S28: Relative difference of aggregated land transport emissions of NH_3 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

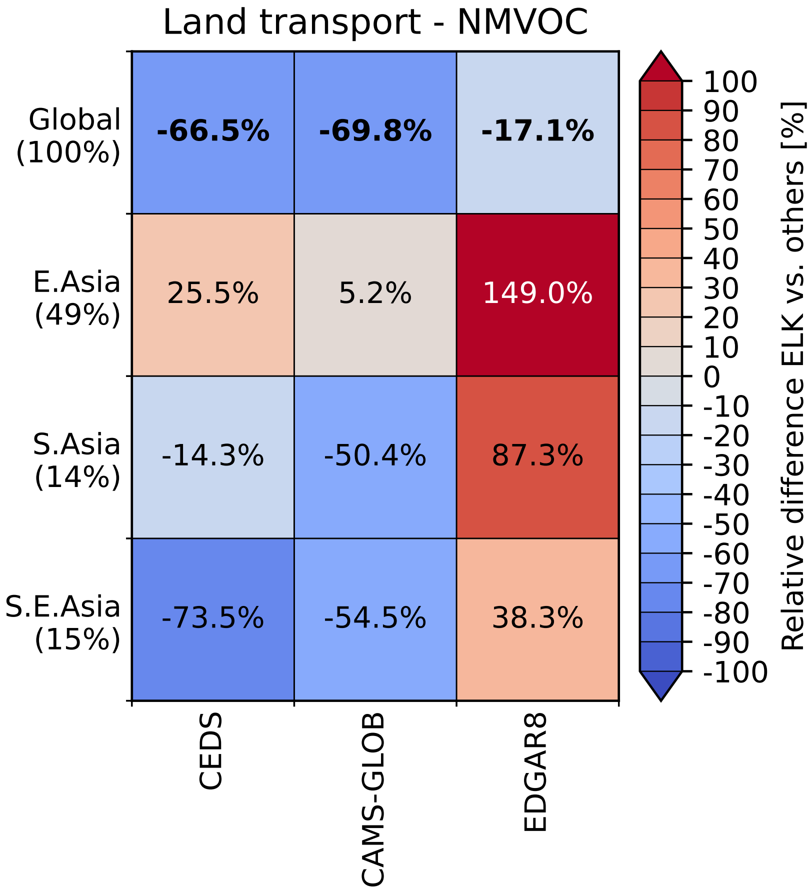


Figure S29: Relative difference of aggregated land transport emissions of NMVOC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

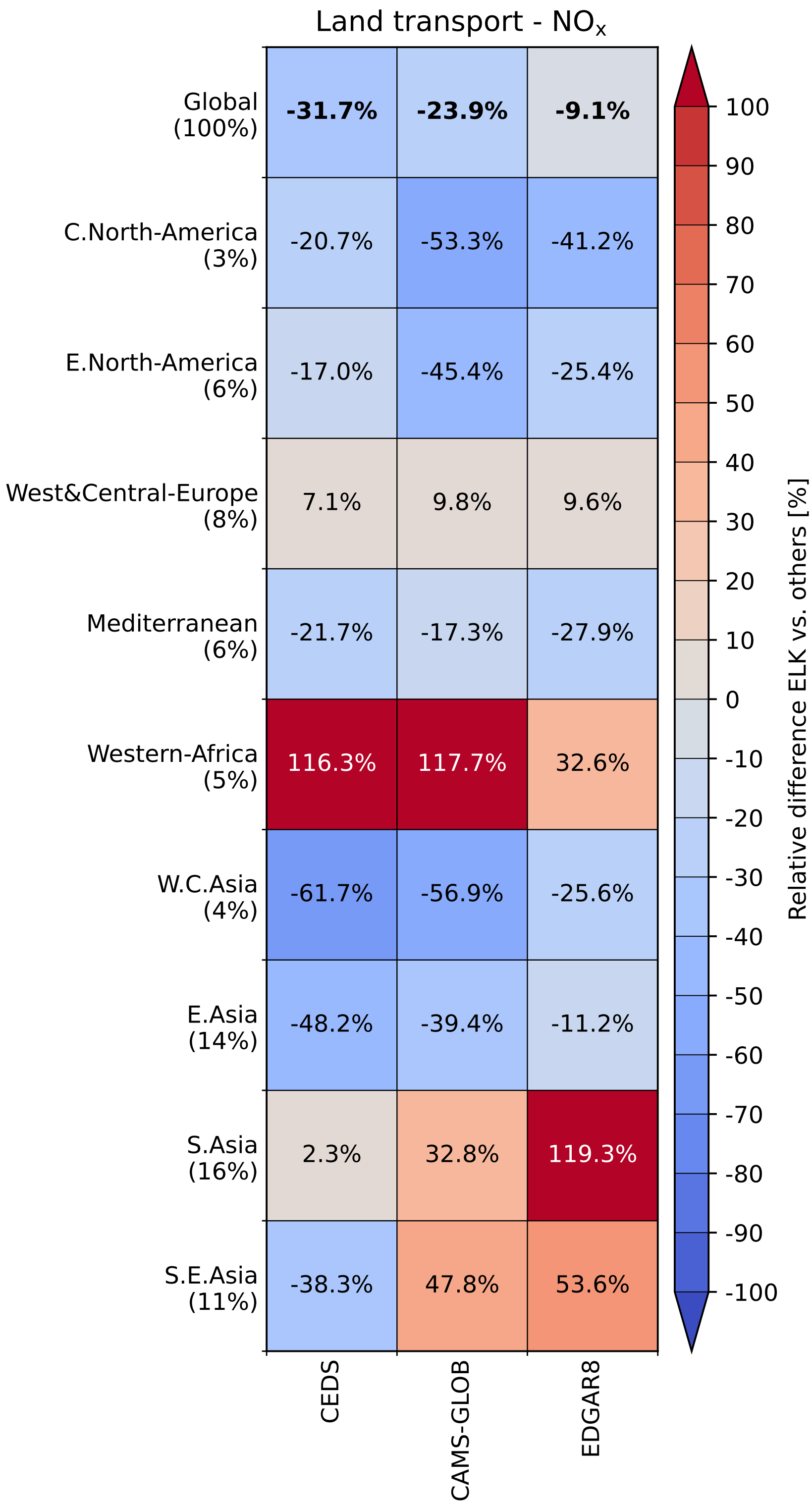


Figure S30: Relative difference of aggregated land transport emissions of NO_x between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

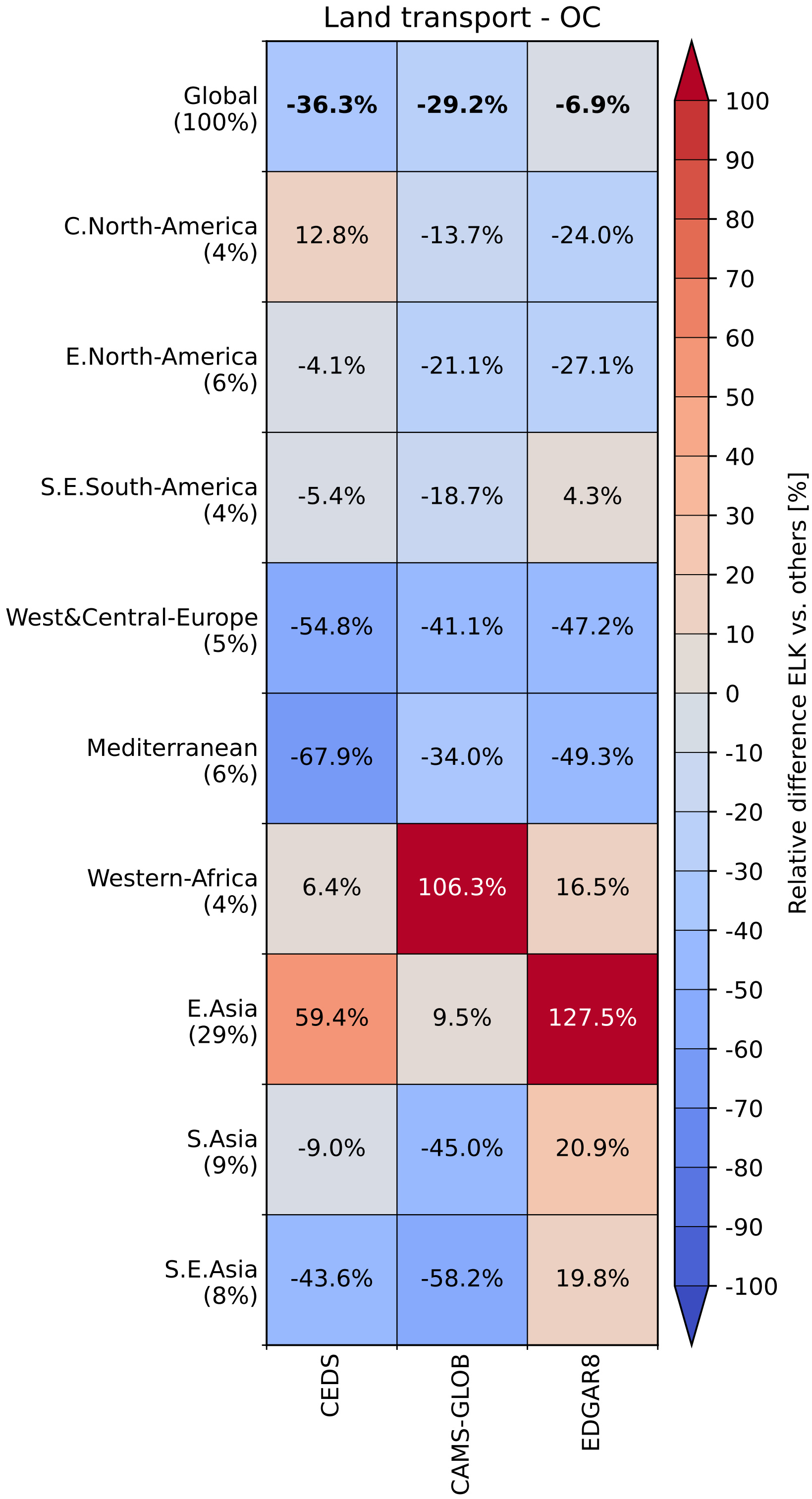


Figure S31: Relative difference of aggregated land transport emissions of OC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

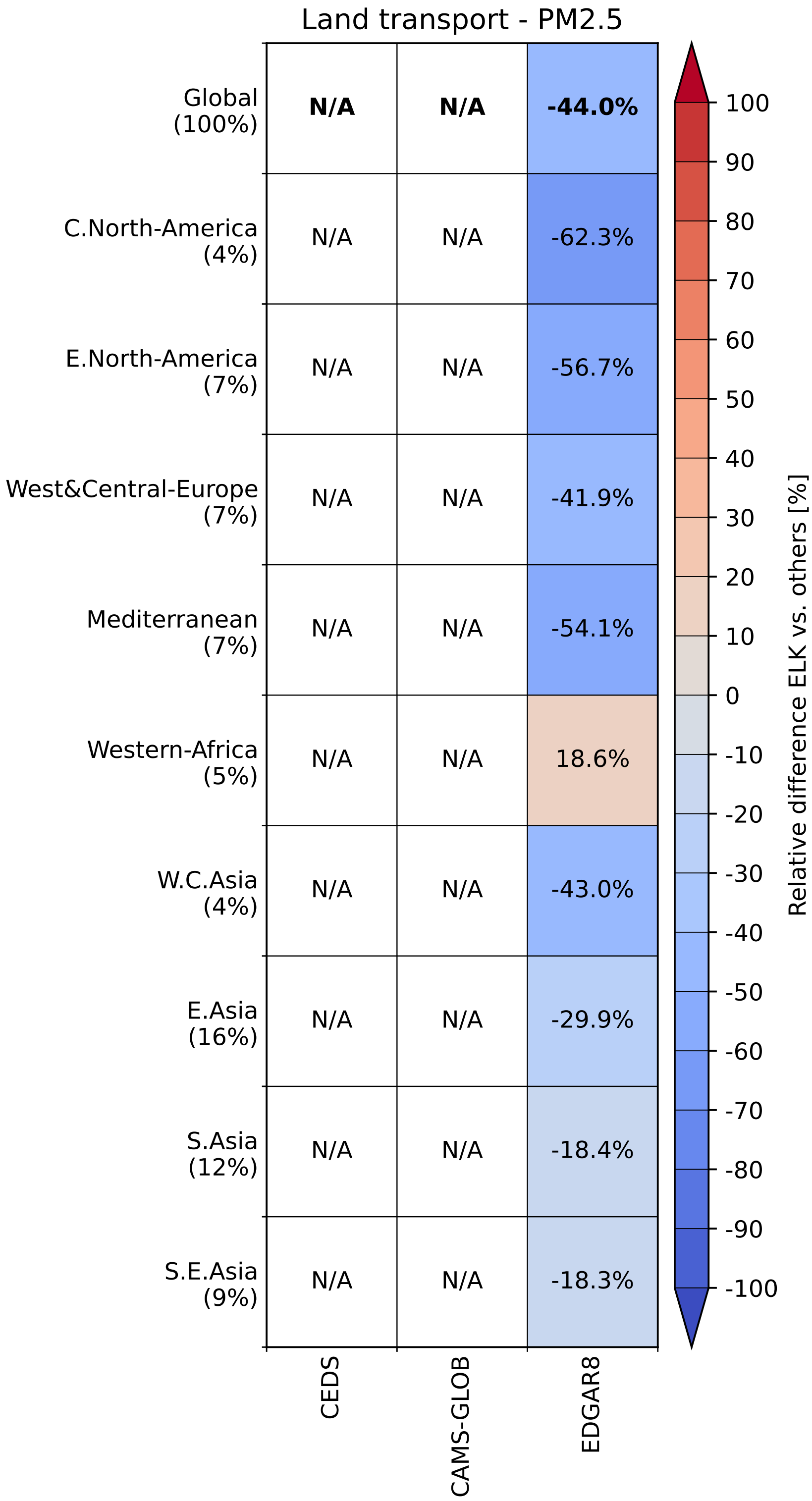


Figure S32: Relative difference of aggregated land transport emissions of $PM_{2.5}$ between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

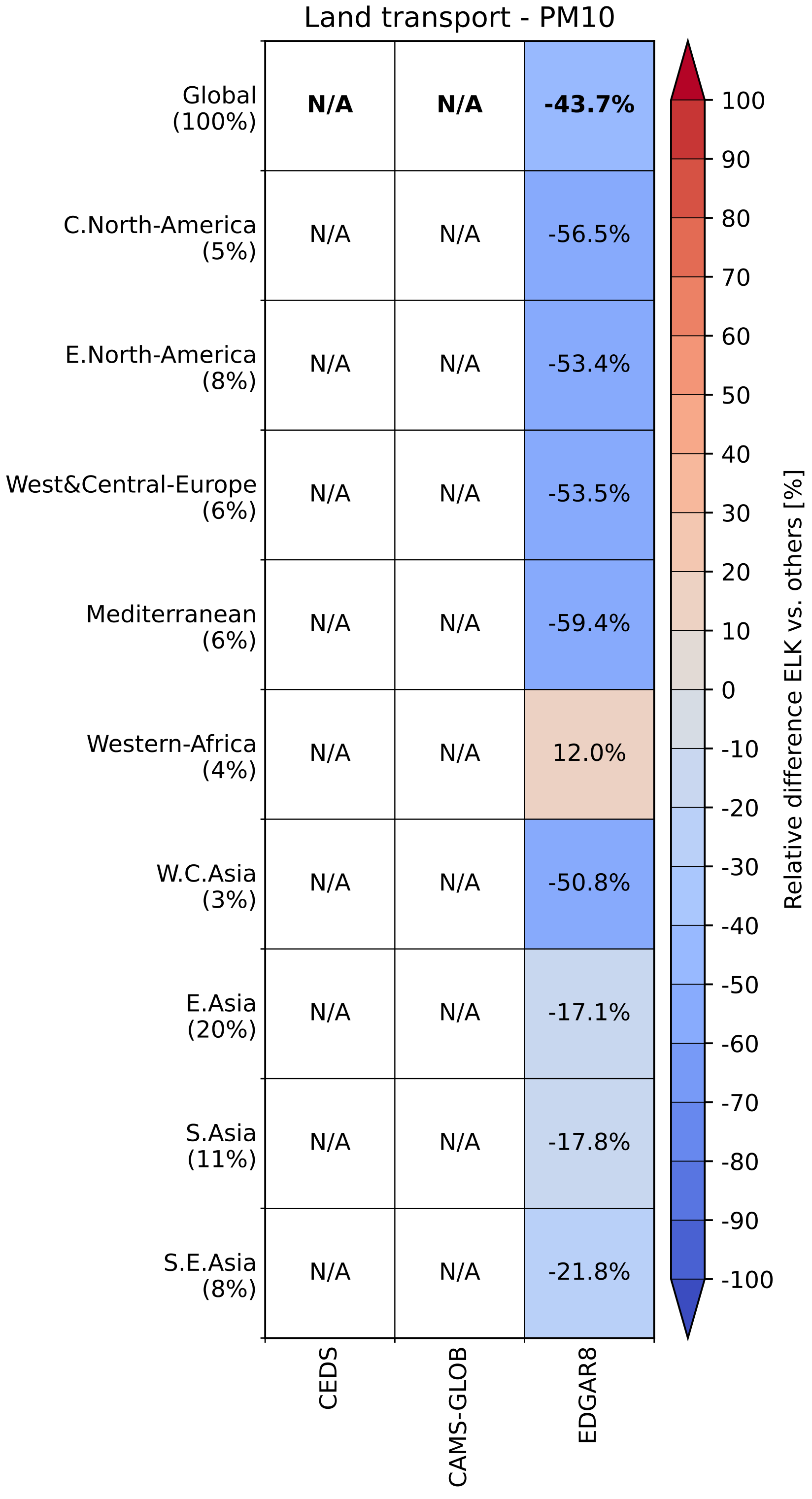


Figure S33: Relative difference of aggregated land transport emissions of PM10 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

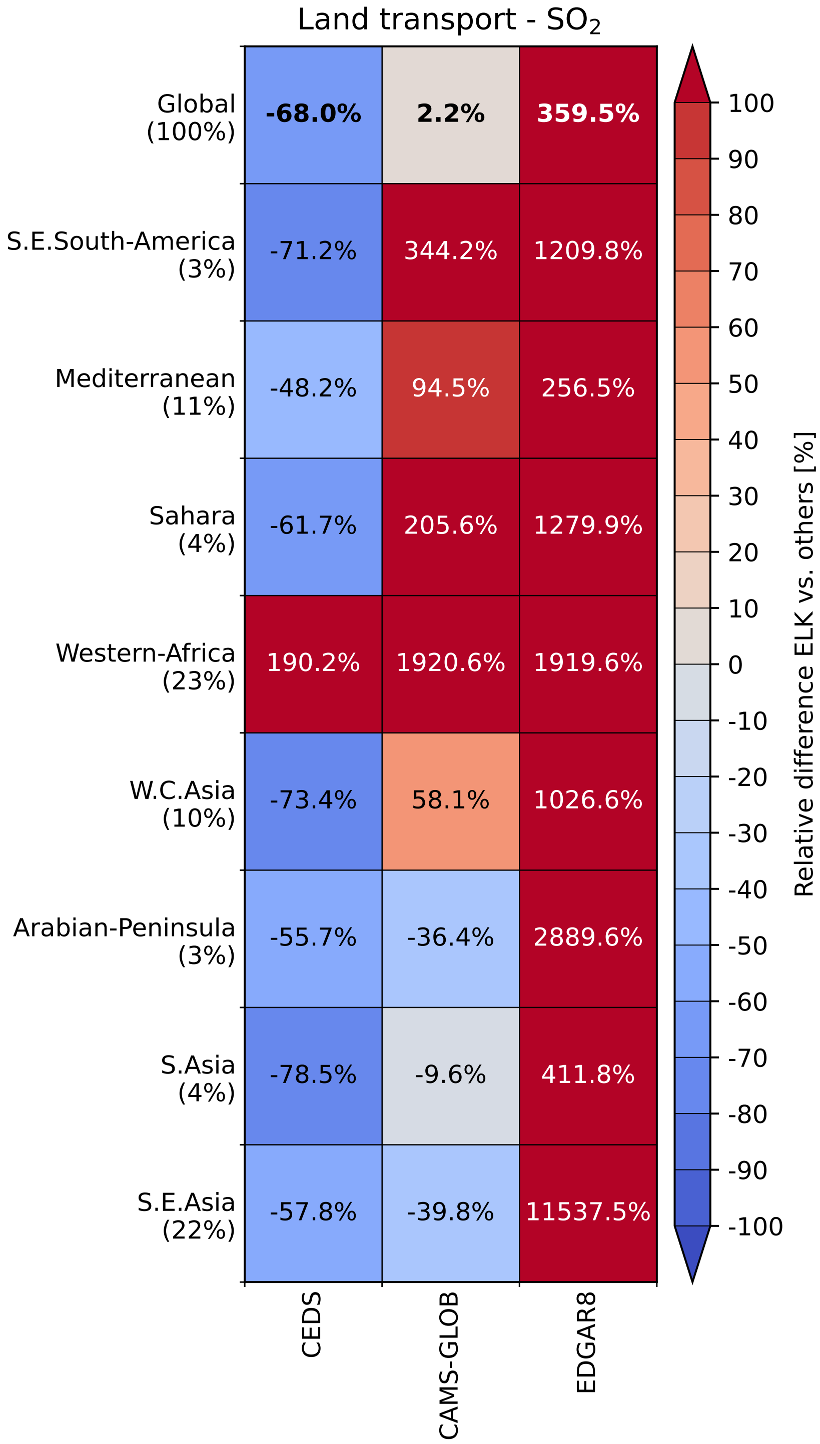


Figure S34: Relative difference of aggregated land transport emissions of SO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS inventory includes domestic navigation as part of the land transport sector.

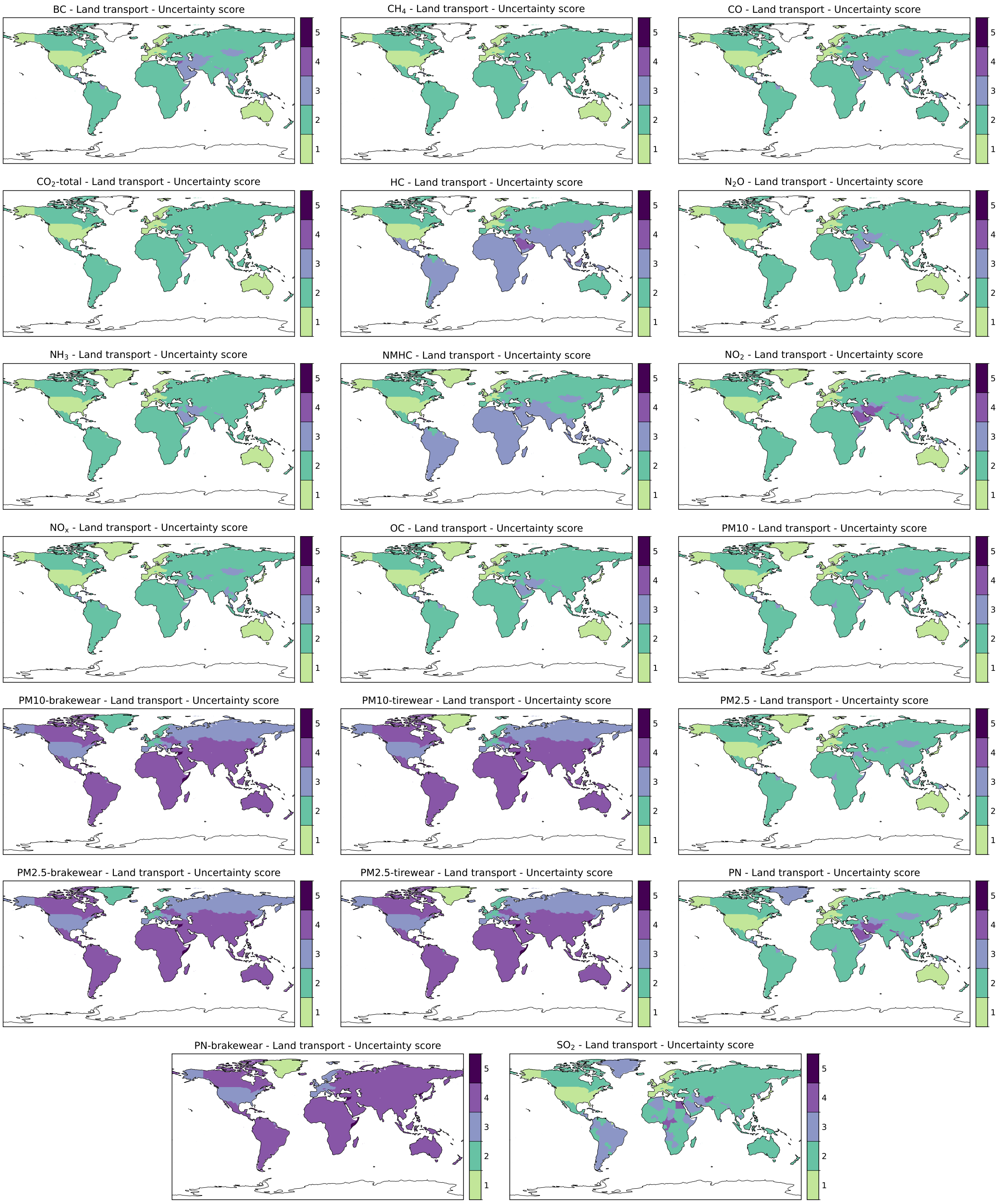


Figure S35: Uncertainty scores for land transport emissions.

3 Results: Shipping

Species	Total shipping		International shipping		Domestic navigation	
BC	0.29	(100%)	0.29	(99.36%)	0.002	(0.64%)
CH_4	0.02	(100%)	0.02	(99.01%)	0.0002	(0.99%)
CO	1.59	(100%)	0.56	(35.07%)	1.03	(64.93%)
CO_2	822.17	(100%)	761.50	(92.62%)	60.66	(7.38%)
N_2O	0.05	(100%)	0.04	(85.74%)	0.007	(14.26%)
NMVOC	0.75	(100%)	0.63	(84.30%)	0.12	(15.70%)
NO_x	13.86	(100%)	12.09	(87.19%)	1.78	(12.81%)
PM_{10}	1.48	(100%)	1.42	(95.59%)	0.07	(4.41%)
SO_x	10.62	(100%)	10.25	(96.52%)	0.37	(3.48%)

Table S5: Globally aggregated emissions of the shipping sector. Units are Tg(species), $Tg(NO_2)$ for NO_x and $Tg(SO_2)$ for SO_x. The percentage figures in brackets are the share by each subsectors to the total shipping emissions.

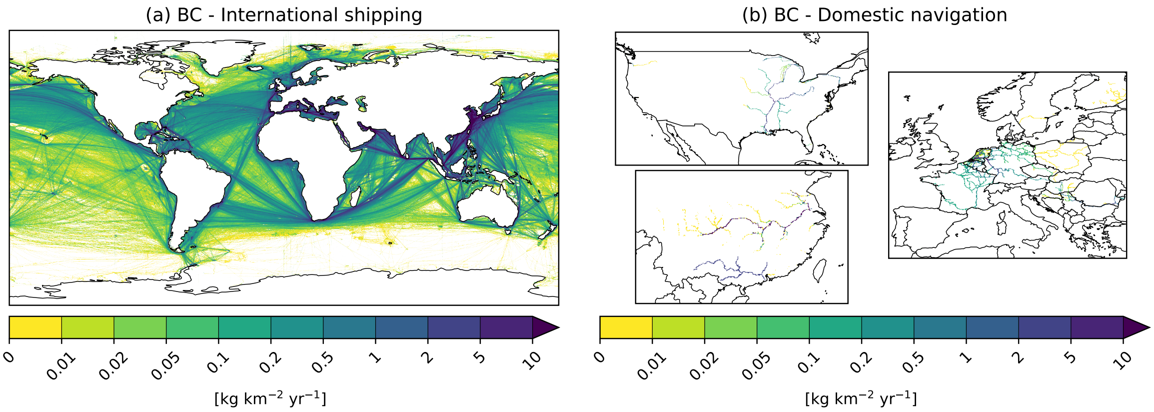


Figure S36: BC emissions from shipping.

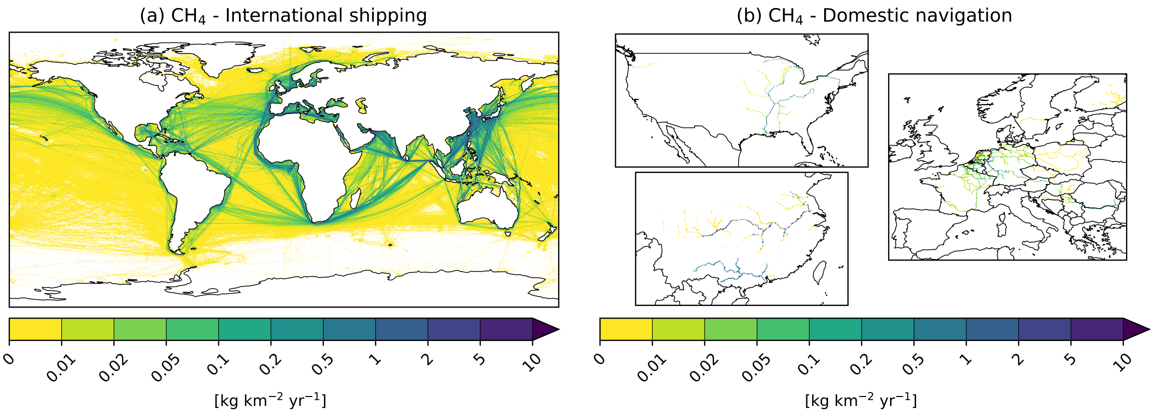


Figure S37: CH_4 emissions from shipping.

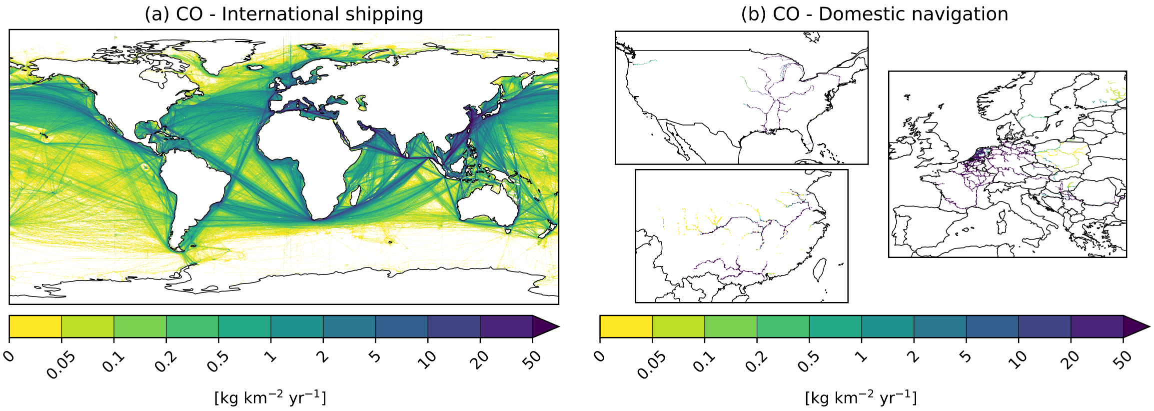


Figure S38: CO emissions from shipping.

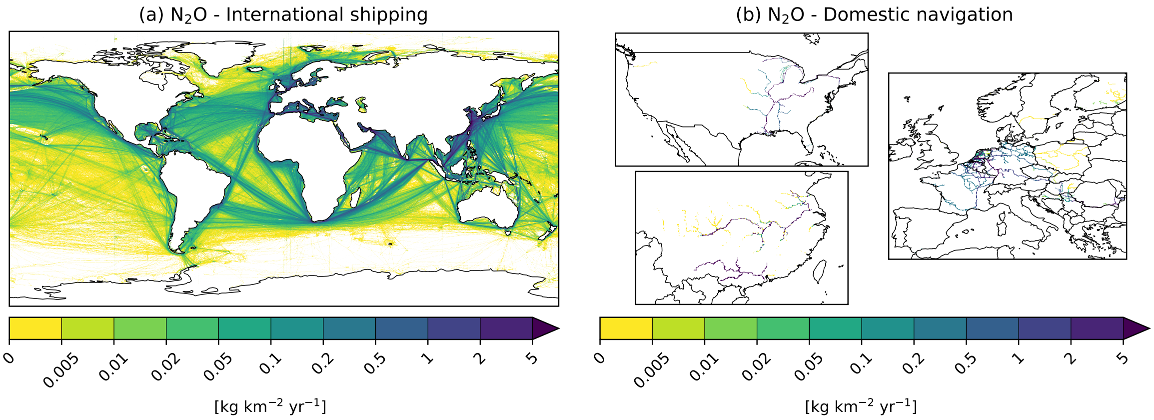


Figure S39: N_2O emissions from shipping.

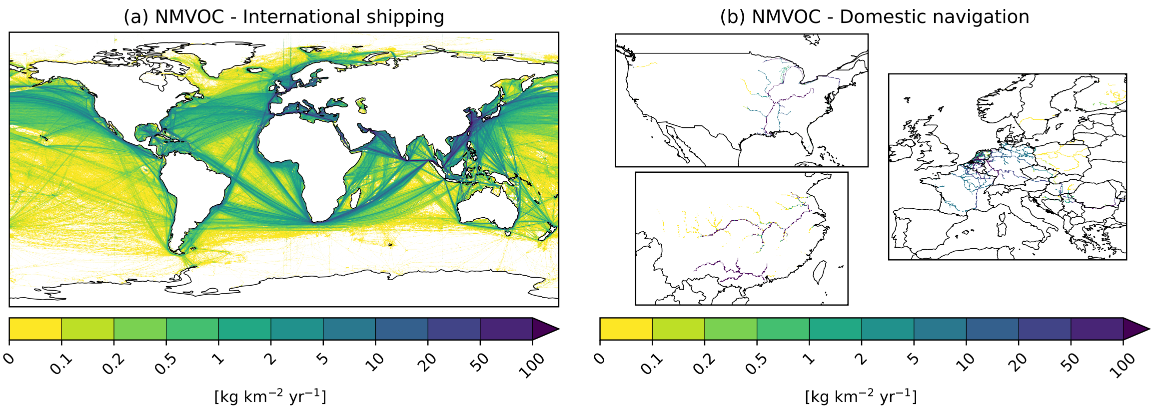


Figure S40: NMVOC emissions from shipping.

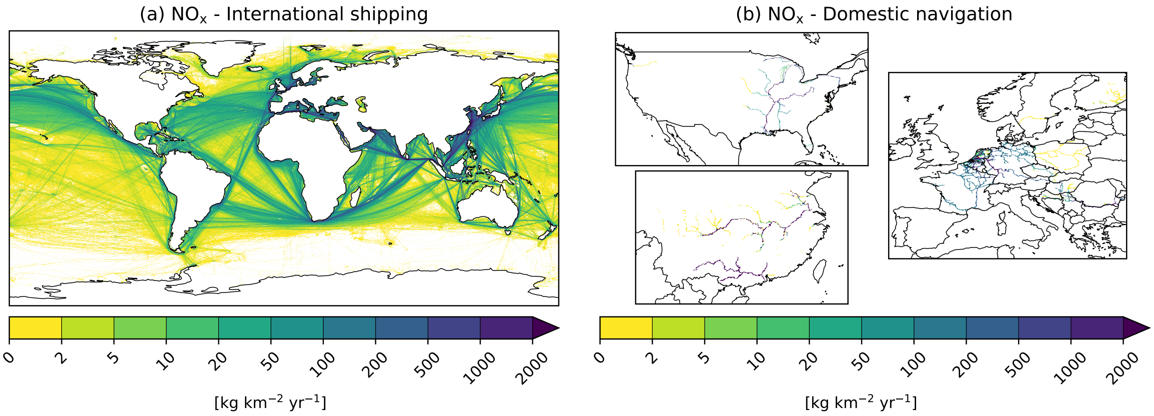


Figure S41: NO_x emissions from shipping.

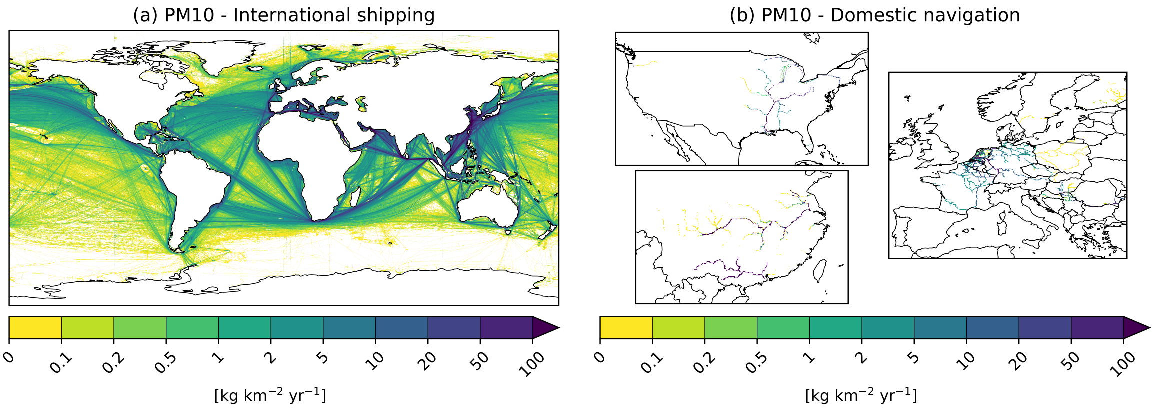


Figure S42: PM_{10} emissions from shipping.

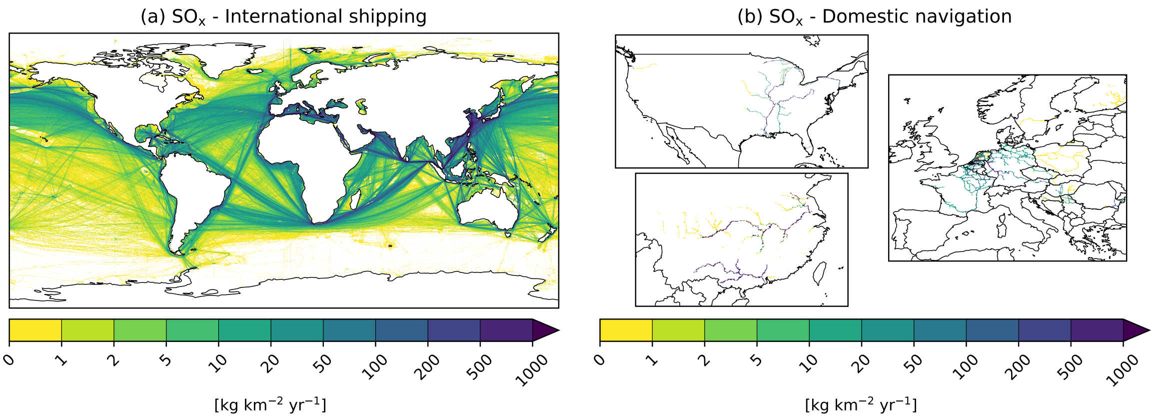


Figure S43: SO_x emissions from shipping.

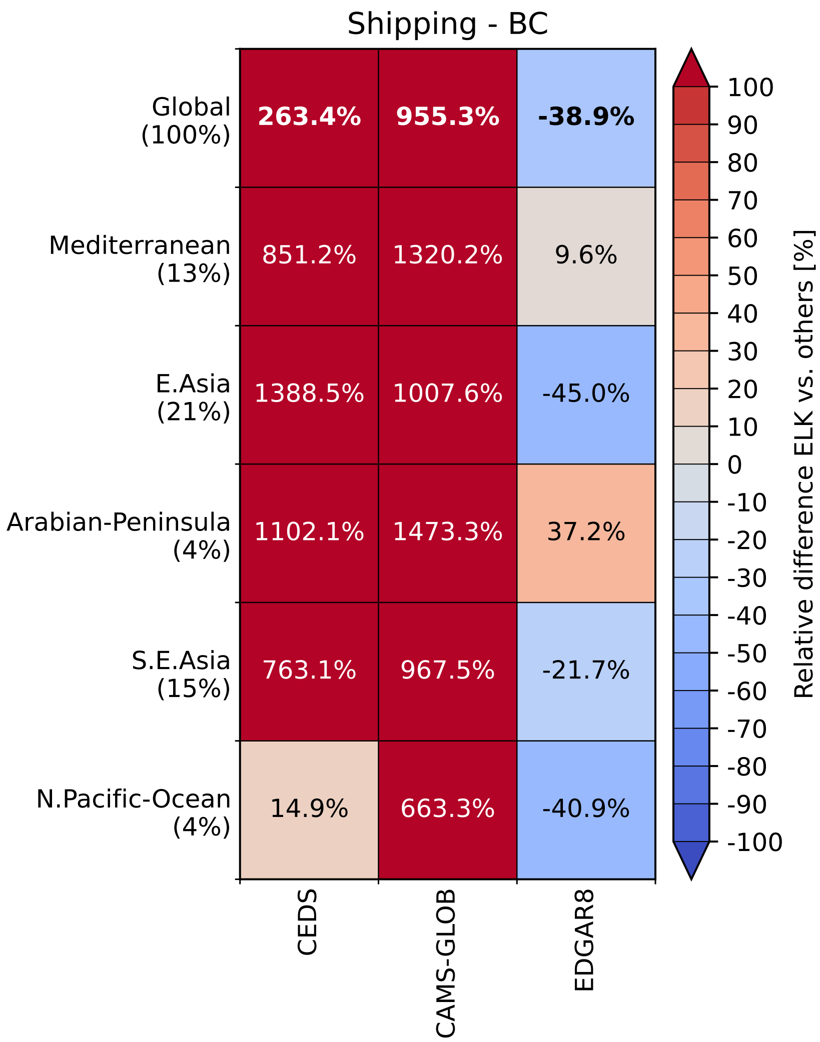


Figure S44: Relative difference of aggregated shipping emissions of BC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

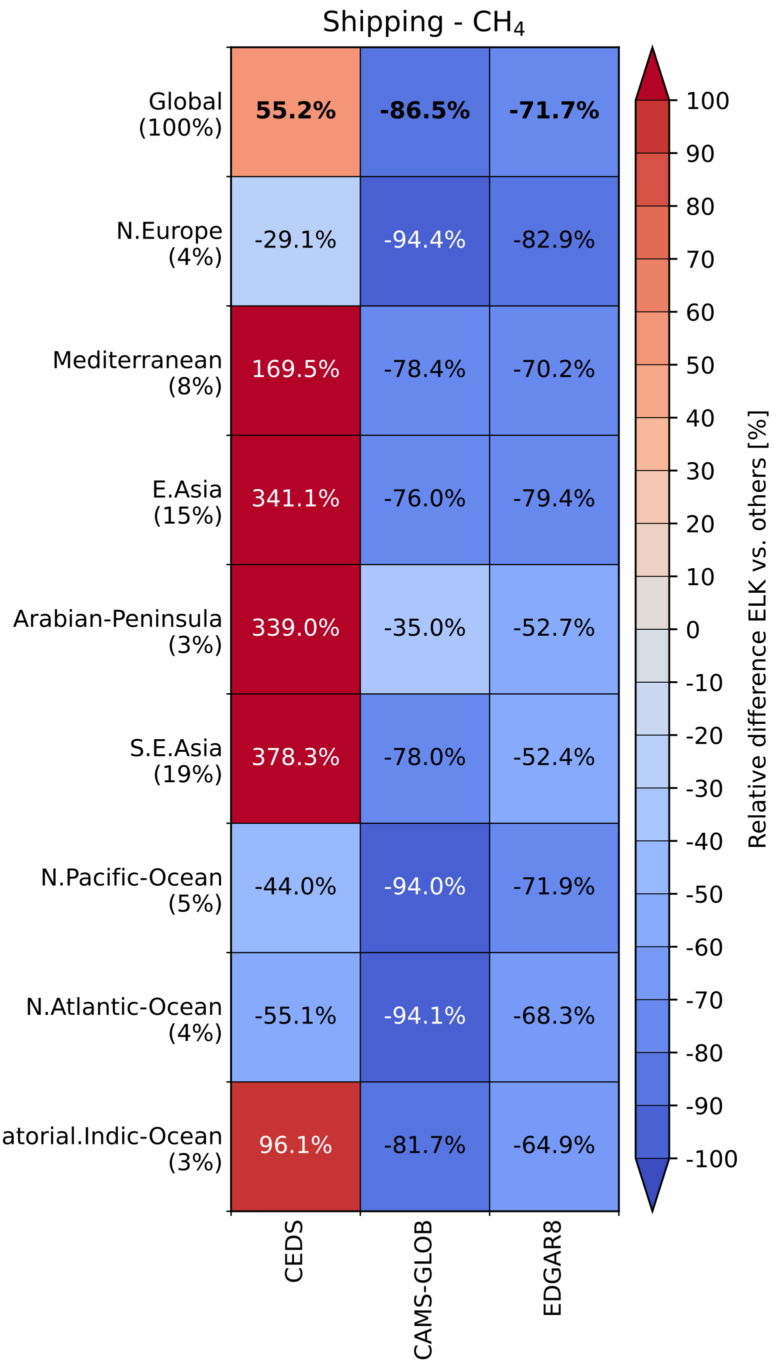


Figure S45: Relative difference of aggregated shipping emissions of CH_4 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

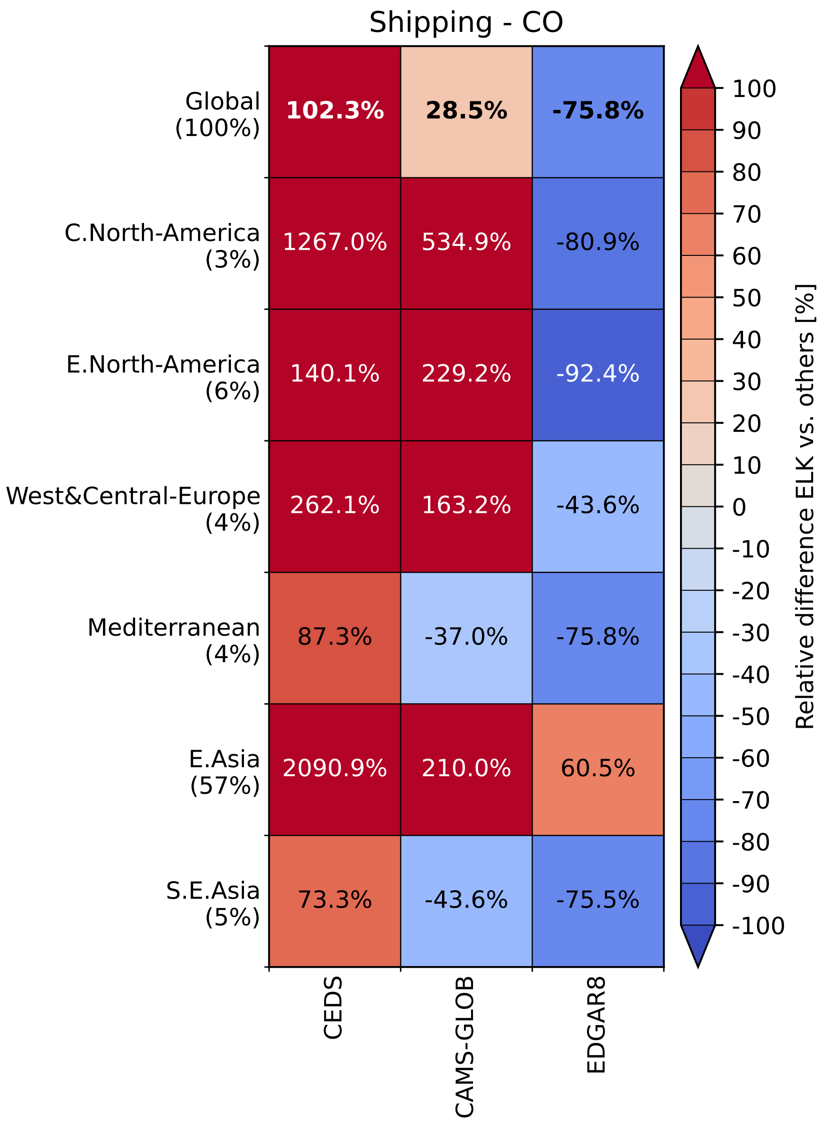


Figure S46: Relative difference of aggregated shipping emissions of CO between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

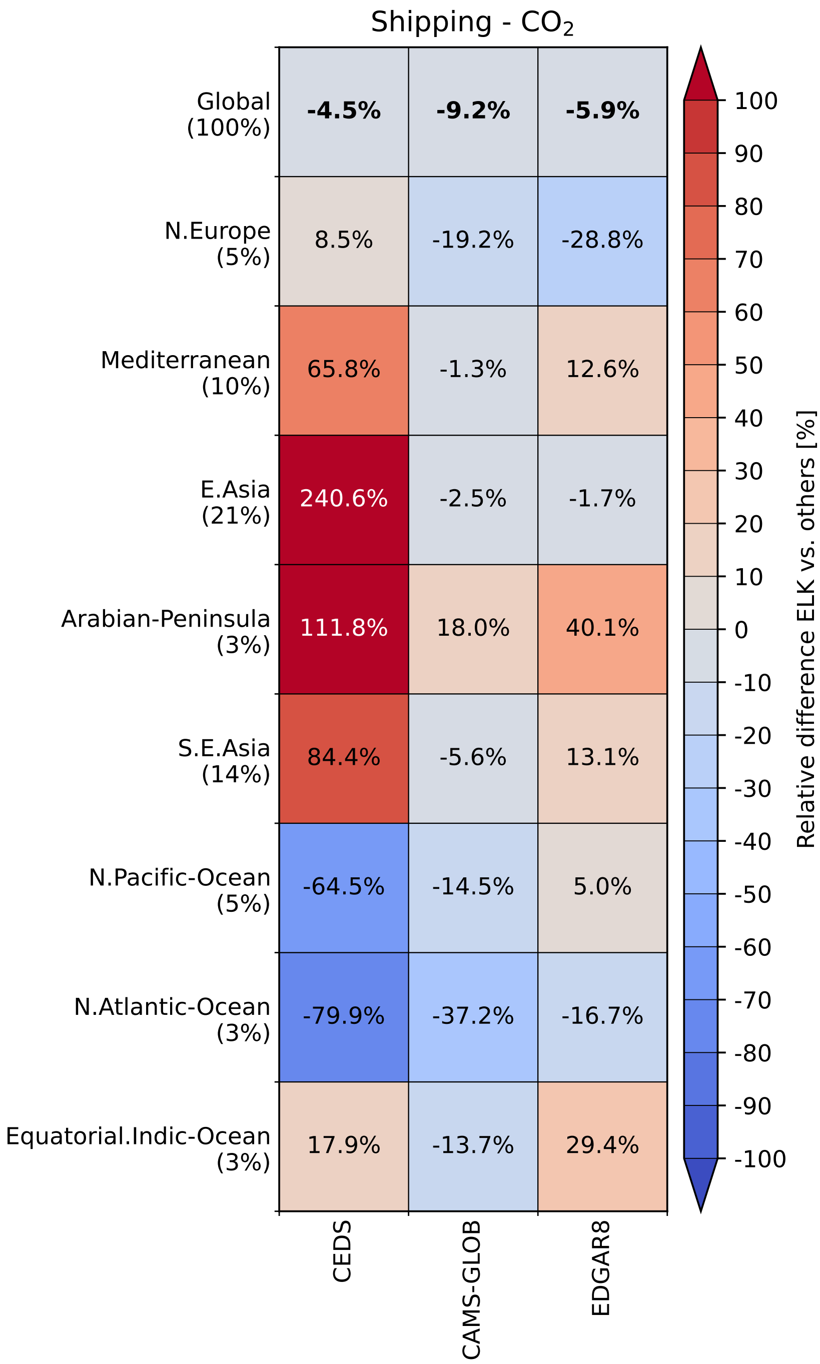


Figure S47: Relative difference of aggregated shipping emissions of CO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

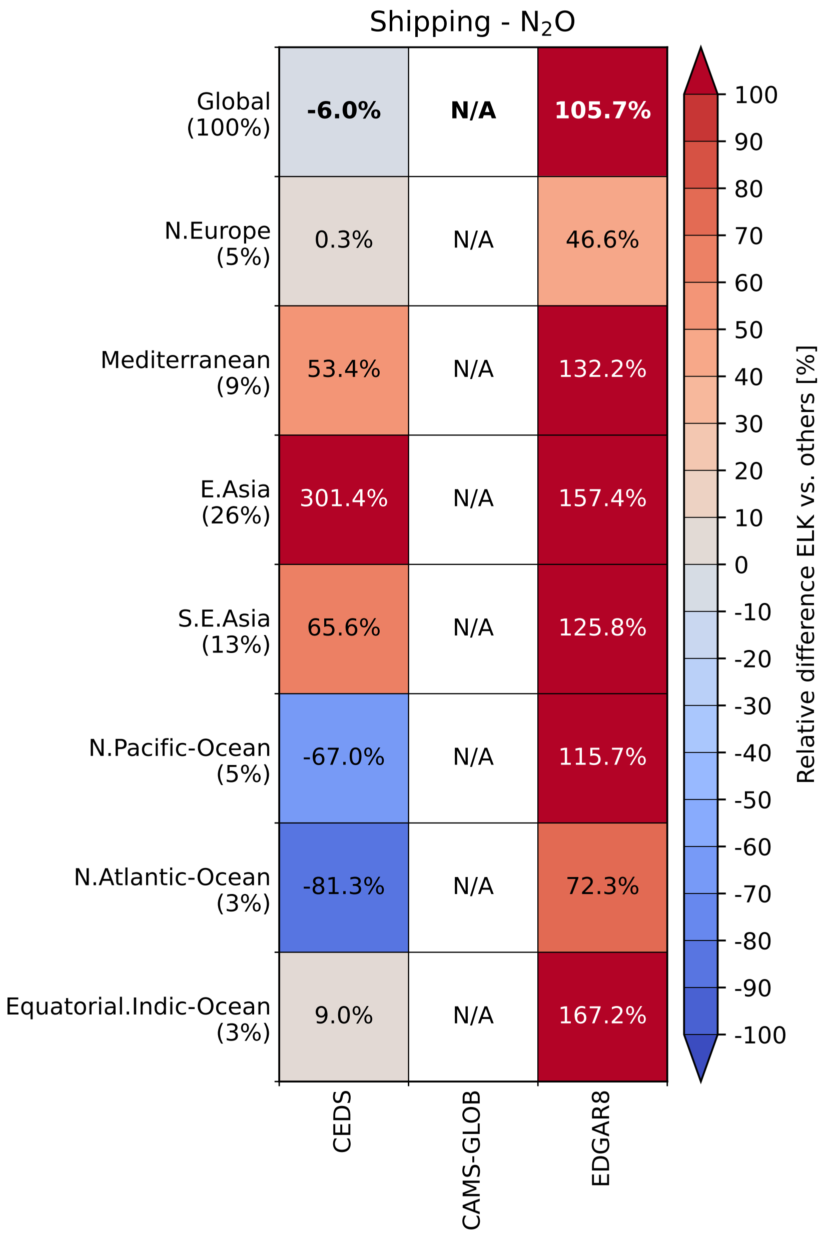


Figure S48: Relative difference of aggregated shipping emissions of N_2O between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

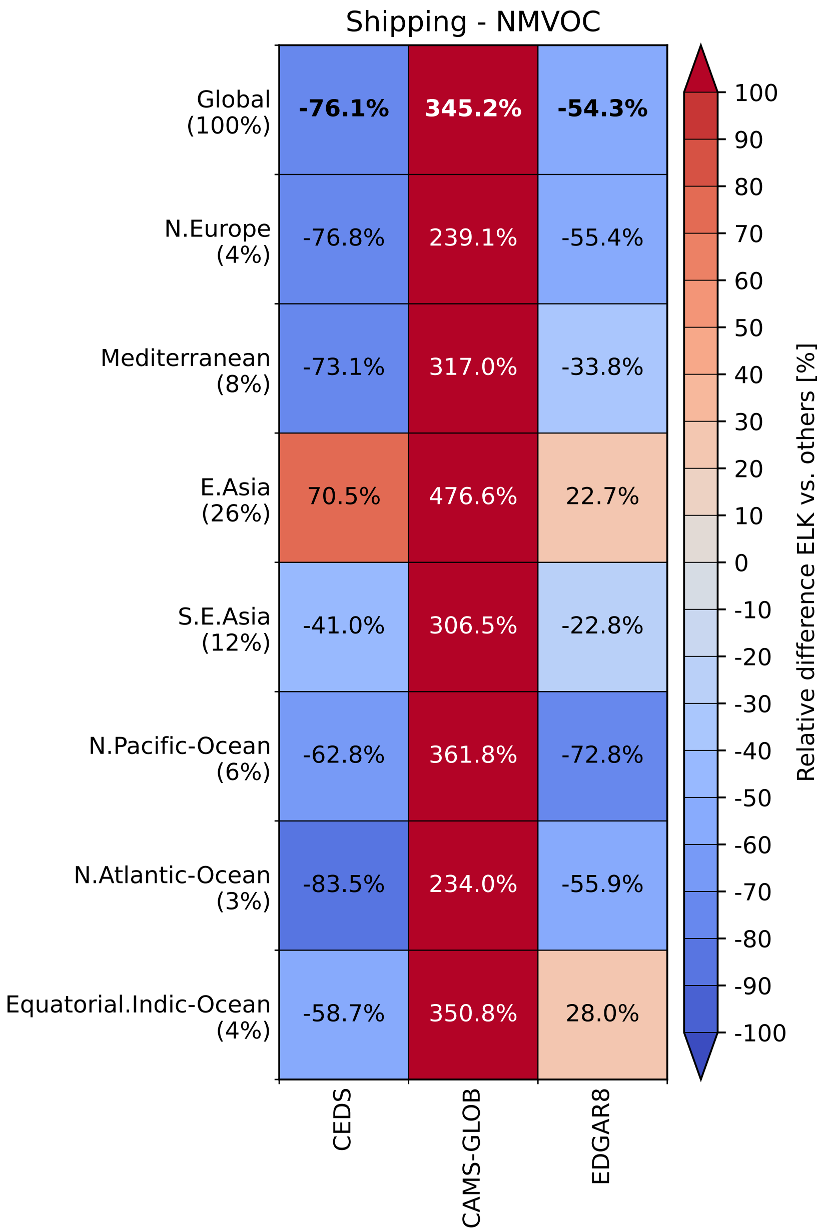


Figure S49: Relative difference of aggregated shipping emissions of NMVOC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

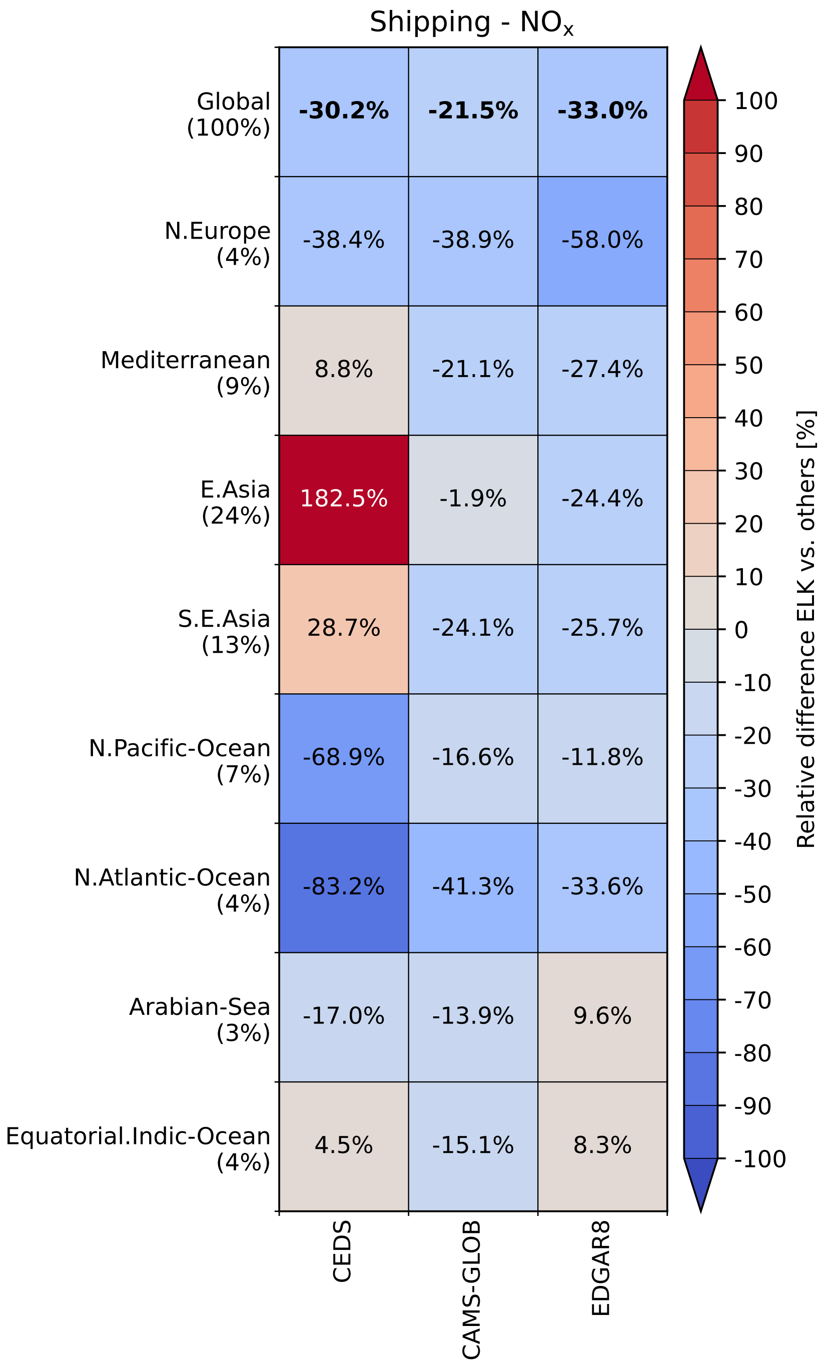


Figure S50: Relative difference of aggregated shipping emissions of NO_x between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

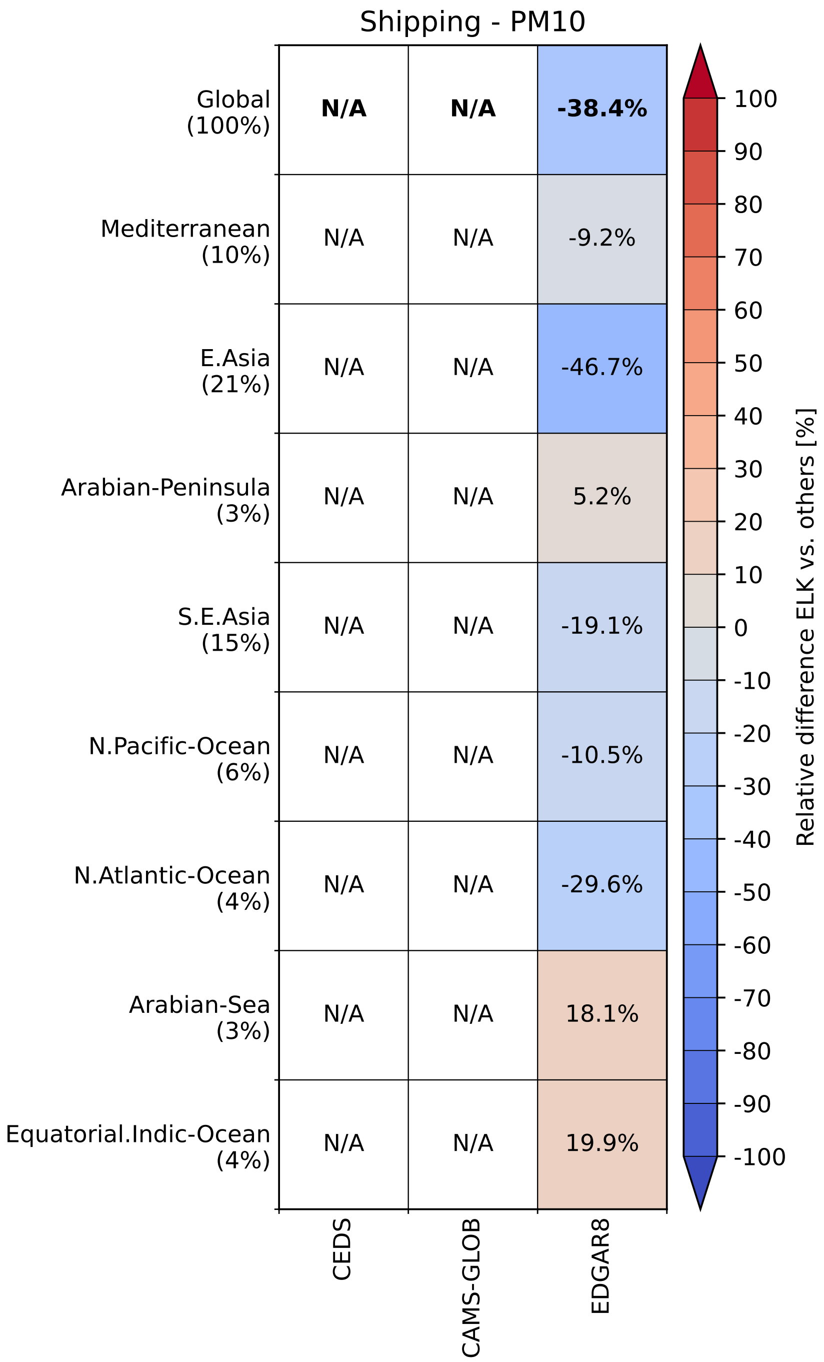


Figure S51: Relative difference of aggregated shipping emissions of PM10 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

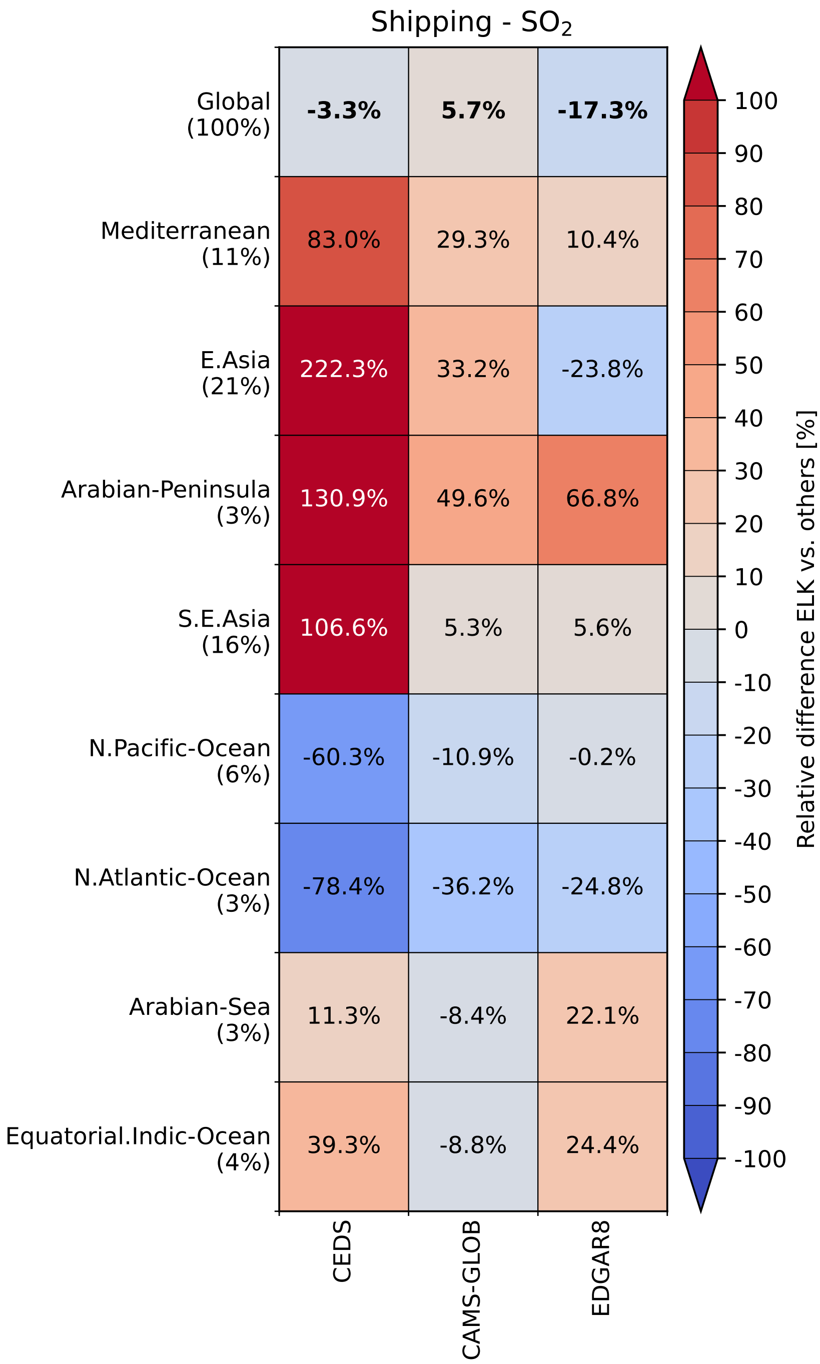


Figure S52: Relative difference of aggregated shipping emissions of SO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot. Note that the CEDS and EDGAR8 inventories does not include domestic navigation in the shipping sector.

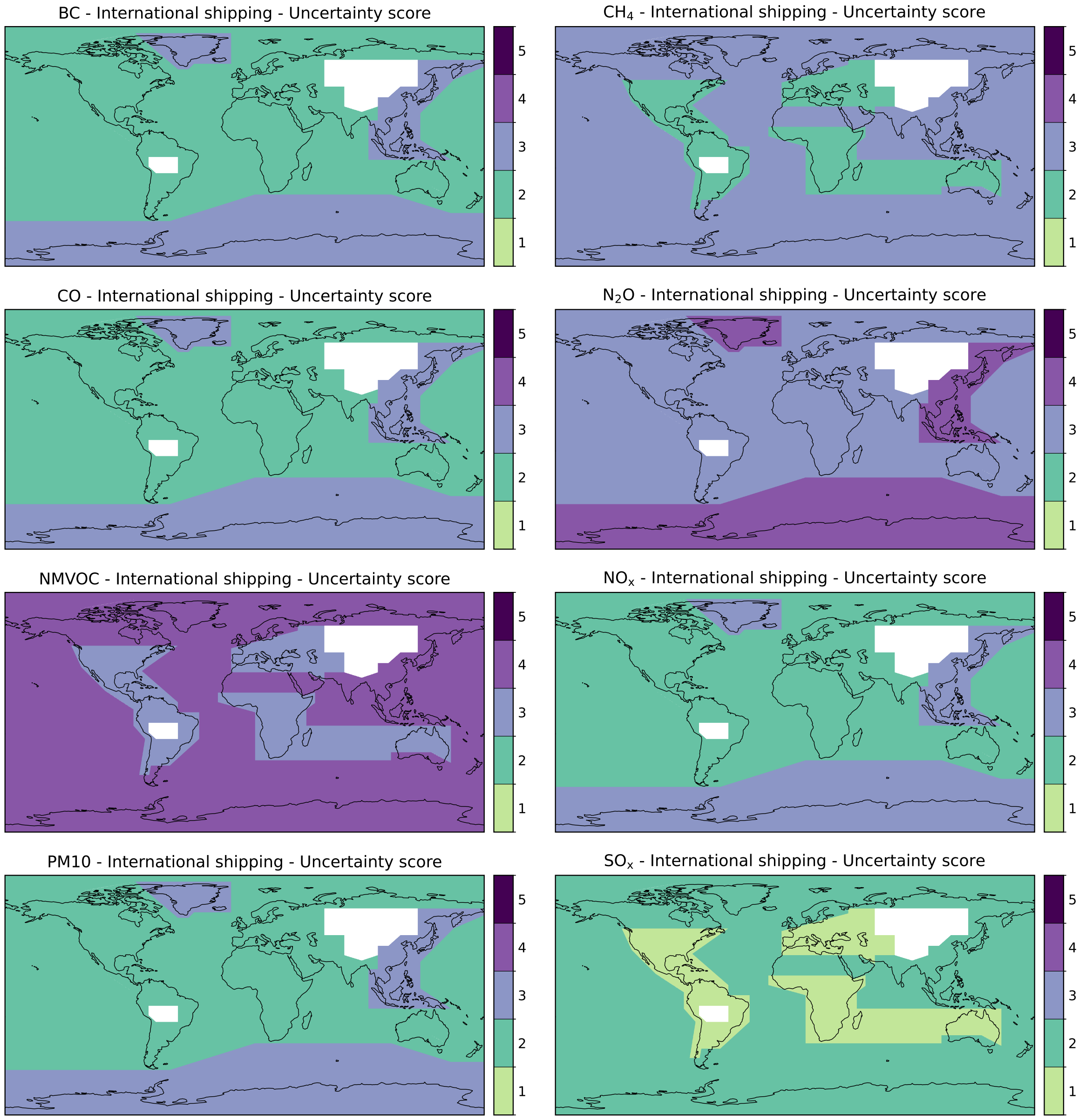


Figure S53: Uncertainty scores for international shipping emissions.

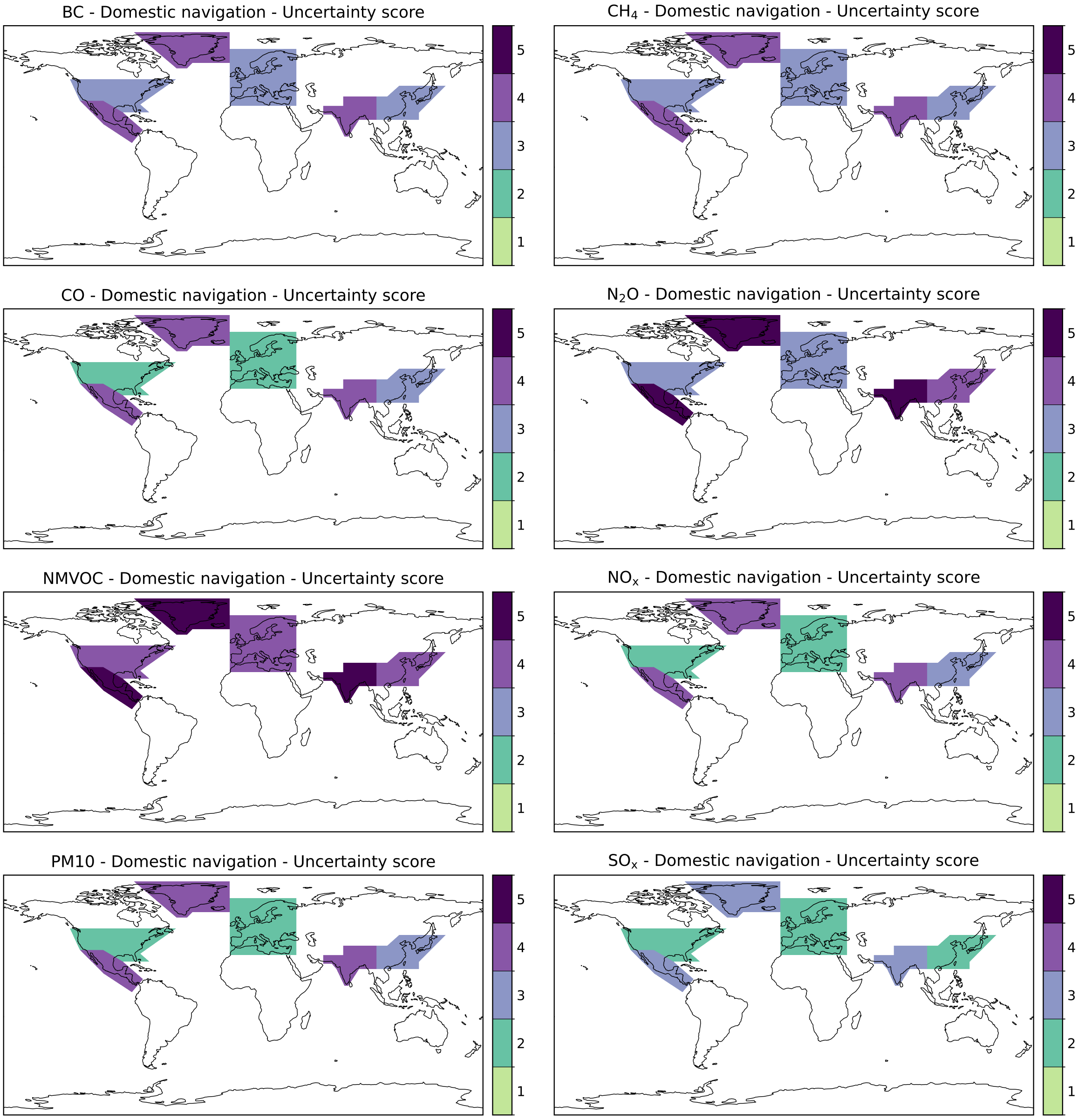


Figure S54: Uncertainty scores for domestic navigation emissions.

4 Results: Aviation

Species/Parameter	Total aviation		Wide-body		Single-aisle	
BC	0.009	(100 %)	0.004	(47.75 %)	0.005	(50.38 %)
CO	0.84	(100 %)	0.21	(24.66 %)	0.54	(64.04 %)
CO_2	851.04	(100 %)	395.01	(46.42 %)	407.62	(47.90 %)
H_2O	333.25	(100 %)	154.68	(46.42 %)	159.62	(47.90 %)
NMVOC	0.08	(100 %)	0.02	(19.51 %)	0.06	(72.17 %)
NO_x	3.74	(100 %)	2.00	(53.42 %)	1.58	(42.16 %)
OC	0.005	(100 %)	0.003	(46.42 %)	0.003	(47.90 %)
SO_2	0.20	(100 %)	0.09	(45.48 %)	0.10	(48.45 %)
nvPMm	0.01	(100 %)	0.004	(41.85 %)	0.005	(51.23 %)
nvPMn	1.18×10^{26}	(100 %)	5.73×10^{25}	(48.46 %)	5.26×10^{25}	(44.53 %)
Fuel consumption	269.40	(100 %)	125.04	(46.42 %)	129.03	(47.90 %)
Flight distance	5.90×10^{13}	(100 %)	1.63×10^{13}	(27.60 %)	3.76×10^{13}	(63.65 %)
Number of flights	38.77	(100 %)	3.30	(8.51 %)	27.77	(71.63 %)
Mean cruise propulsion efficiency	0.30		0.35		0.30	

Species/Parameter	Regional		Cargo	
BC	3e-05	(0.36 %)	0.0001	(1.51 %)
CO	0.08	(9.78 %)	0.01	(1.52 %)
CO_2	26.16	(3.07 %)	22.24	(2.61 %)
H_2O	10.24	(3.07 %)	8.71	(2.61 %)
NMVOC	0.006	(7.10 %)	0.001	(1.22 %)
NO_x	0.08	(2.19 %)	0.08	(2.23 %)
OC	0.0002	(3.07 %)	0.0001	(2.61 %)
SO_2	0.006	(3.29 %)	0.005	(2.78 %)
nvPMm	0.0004	(3.54 %)	0.0003	(3.39 %)
nvPMn	4.26×10^{24}	(3.61 %)	4.02×10^{24}	(3.40 %)
Fuel consumption	8.28	(3.07 %)	7.04	(2.61 %)
Flight distance	3.82×10^{12}	(6.47 %)	1.34×10^{12}	(2.28 %)
Number of flights	7.44	(19.19 %)	0.26	(0.67 %)
Mean cruise propulsion efficiency	0.29		0.32	

Table S6: Globally aggregated emissions of the aviation sector. Species units are Tg(species), Tg(NO_2) for NO_x and particles for nvPMn. Fuel consumption is in Tg, flight distance in m, number of flights in millions. Propulsion efficiency is dimensionless. The percentage figures in brackets are the share by each subsectors to the total aviation emissions.

Region	Total aviation	Wide-body	Single-aisle	Regional	Cargo	Earth fraction
Northern Hemisphere	90.62	89.80	91.34	89.72	93.15	50.00
Southern Hemisphere	9.38	10.20	8.66	10.28	6.85	50.00
Africa	2.73	3.69	1.68	4.74	2.59	7.34
Asia	35.72	38.81	33.96	13.94	38.56	13.22
Central America	3.11	1.24	4.98	2.93	2.17	1.98
Europe	21.01	16.77	25.29	16.59	23.06	3.70
North America	19.51	12.35	24.58	55.03	12.17	5.26
Oceania	2.64	3.50	1.81	3.22	1.84	4.09
Polar regions	0.79	1.50	0.12	0.23	1.17	4.97
South America	3.74	2.66	4.86	2.22	4.12	4.99
Land domains total	89.25	80.52	97.28	98.90	85.68	45.55
Arctic	0.22	0.46	0.00	0.00	0.26	1.24
Atlantic Ocean	5.22	9.73	0.97	0.30	8.59	10.46
Indian Ocean	1.66	2.83	0.66	0.29	0.97	6.43
Pacific Ocean	3.62	6.39	1.08	0.50	4.52	26.26
Southern Ocean	0.05	0.11	0.00	0.00	0.02	10.08
Ocean domains total	10.77	19.52	2.71	1.09	14.36	54.47

Table S7: Regional share of fuel burn and CO_2 emission from aviation and from the four subsectors. The definition of regions is taken from Weder et al. (2025).

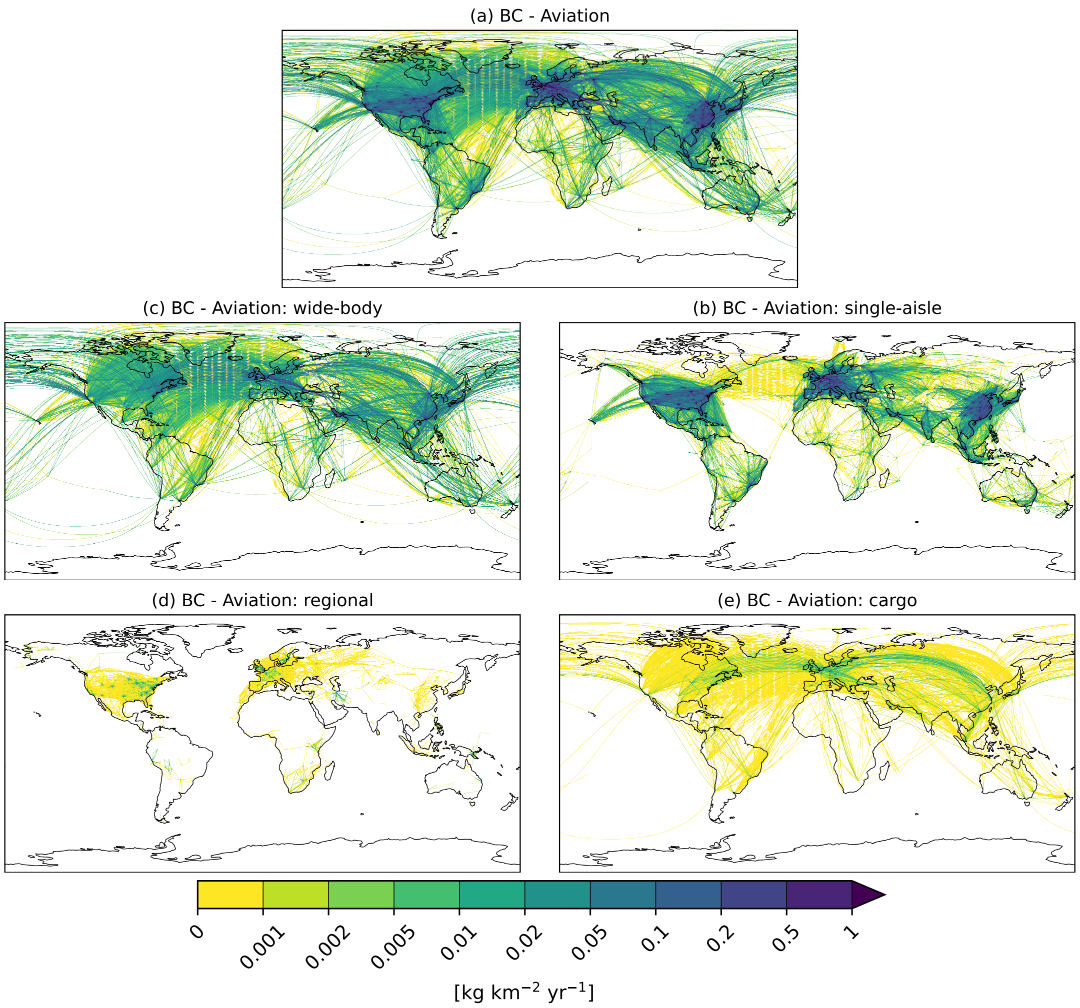


Figure S55: Vertically integrated BC emissions from aviation.

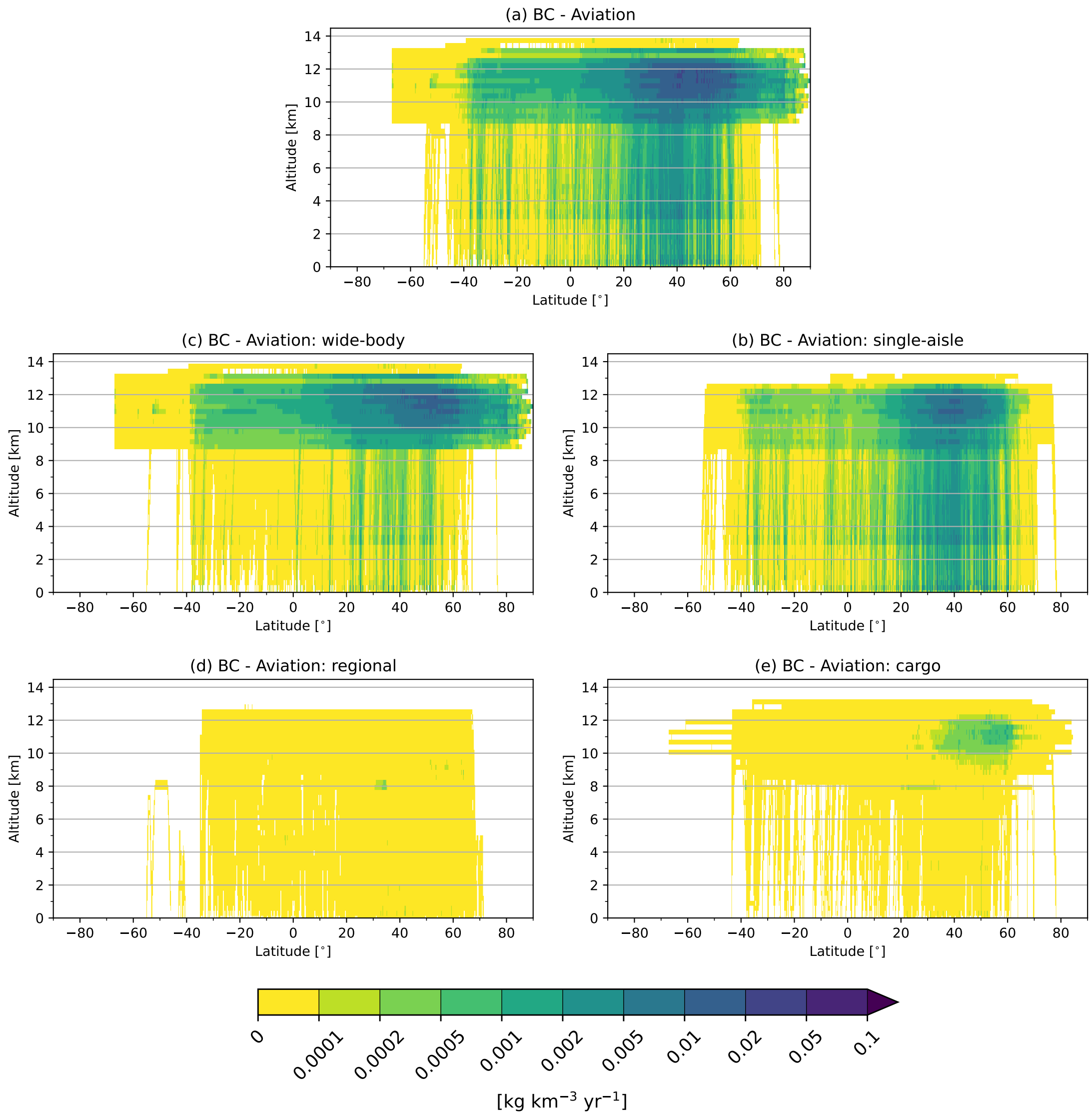


Figure S56: Zonally averaged BC emissions from aviation.

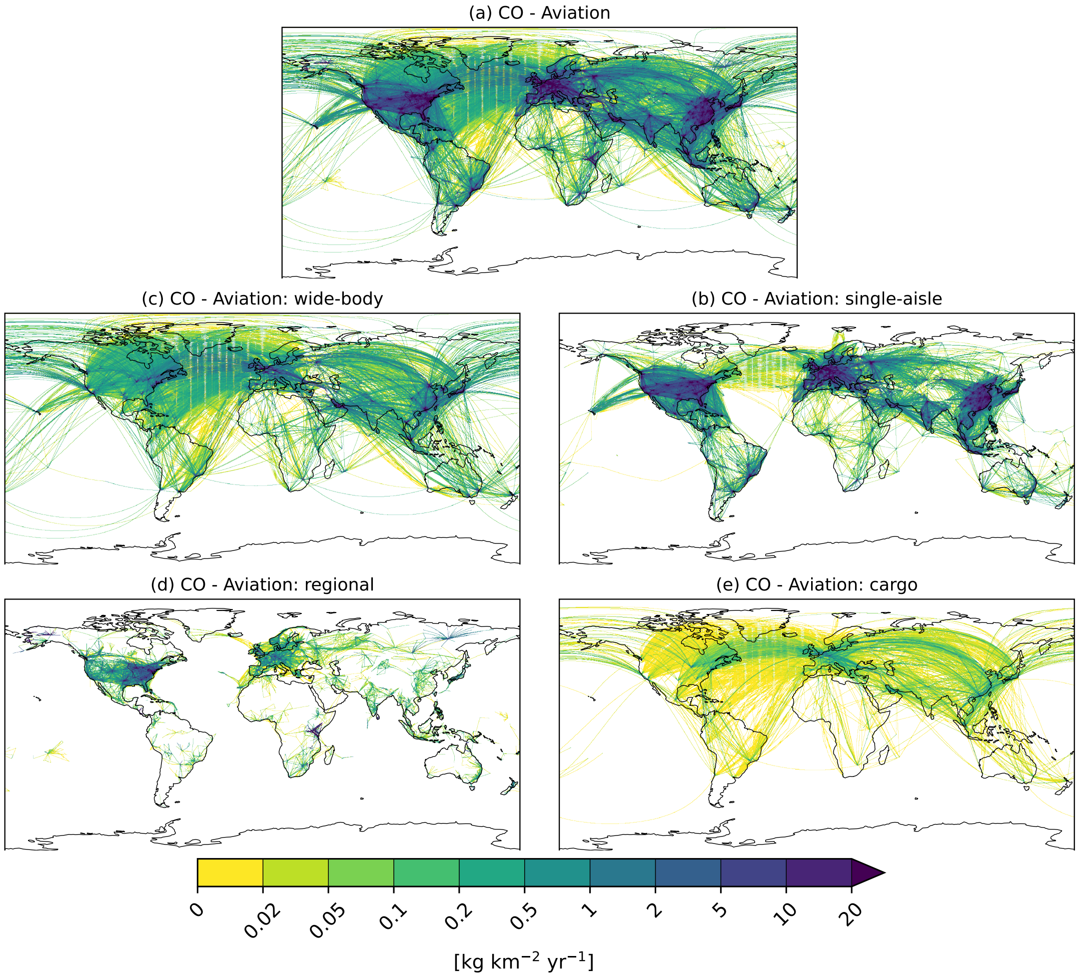


Figure S57: Vertically integrated CO emissions from aviation.

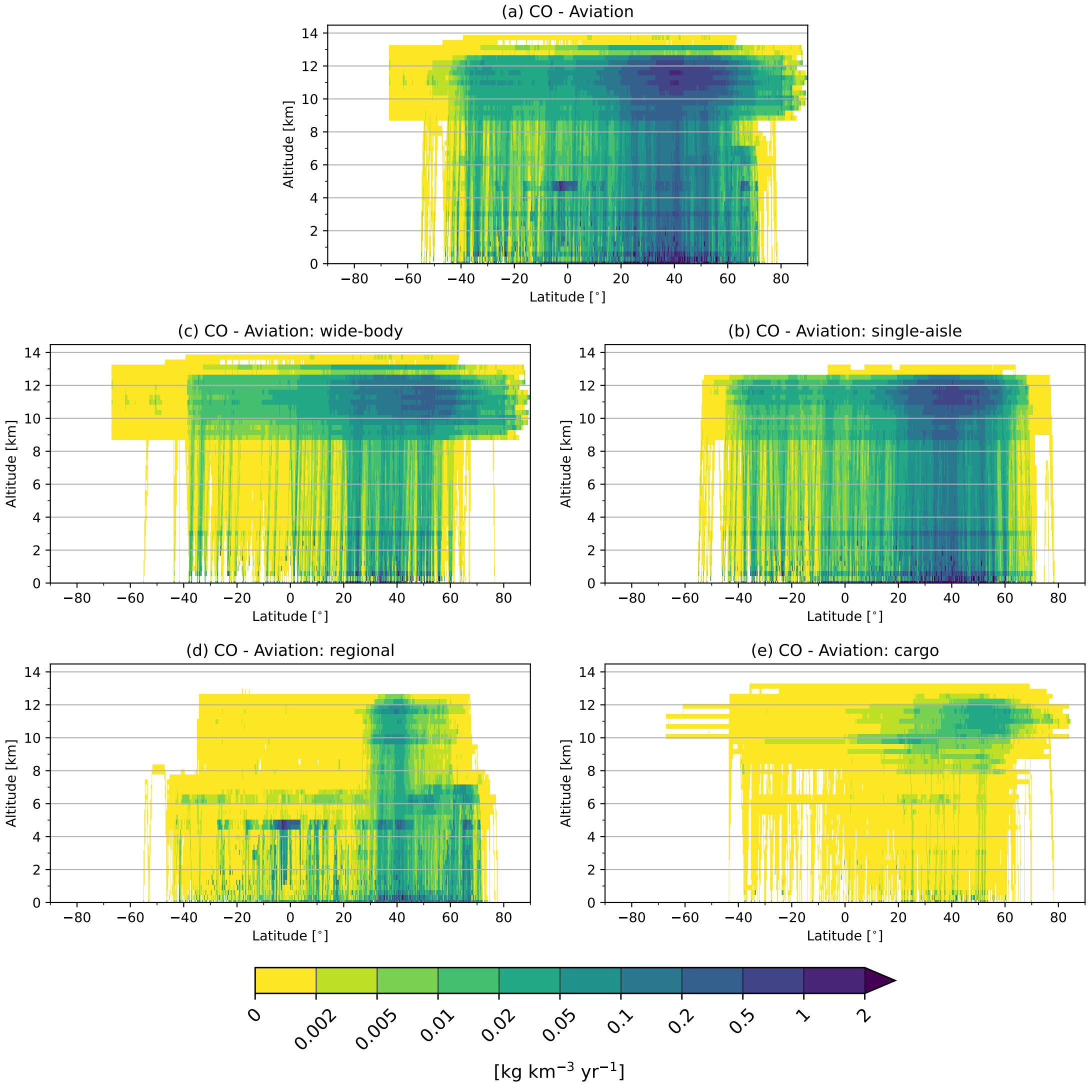


Figure S58: Zonally averaged CO emissions from aviation.

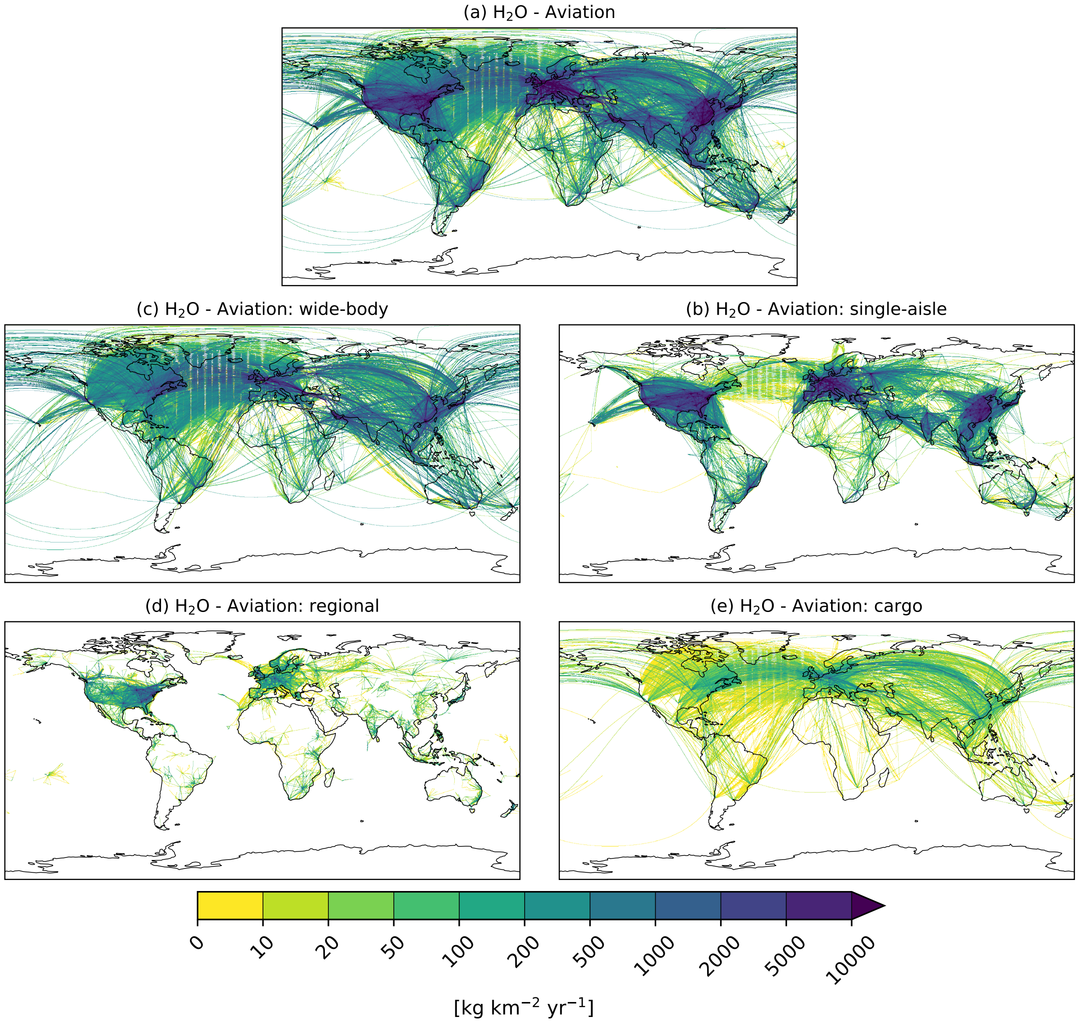


Figure S59: Vertically integrated H_2O emissions from aviation.

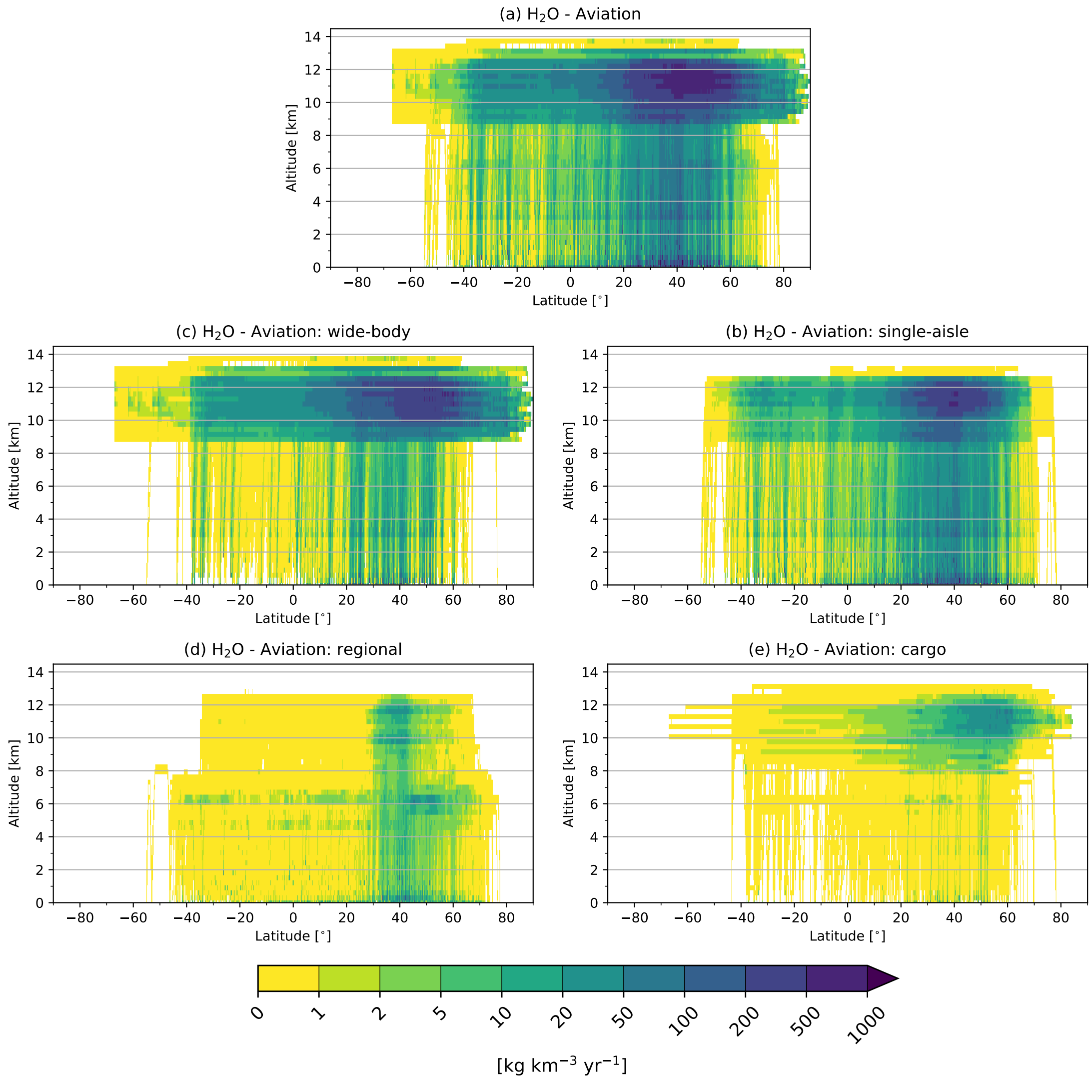


Figure S60: Zonally averaged H_2O emissions from aviation.

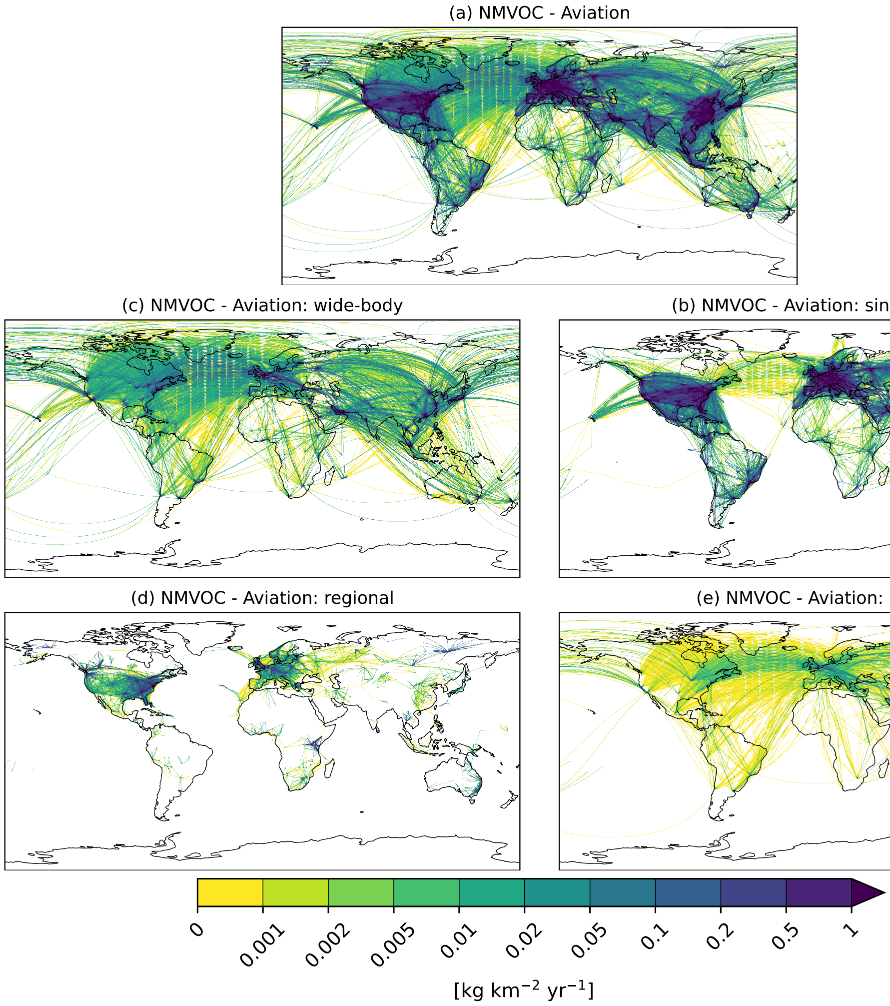


Figure S61: Vertically integrated NMVOC emissions from aviation.

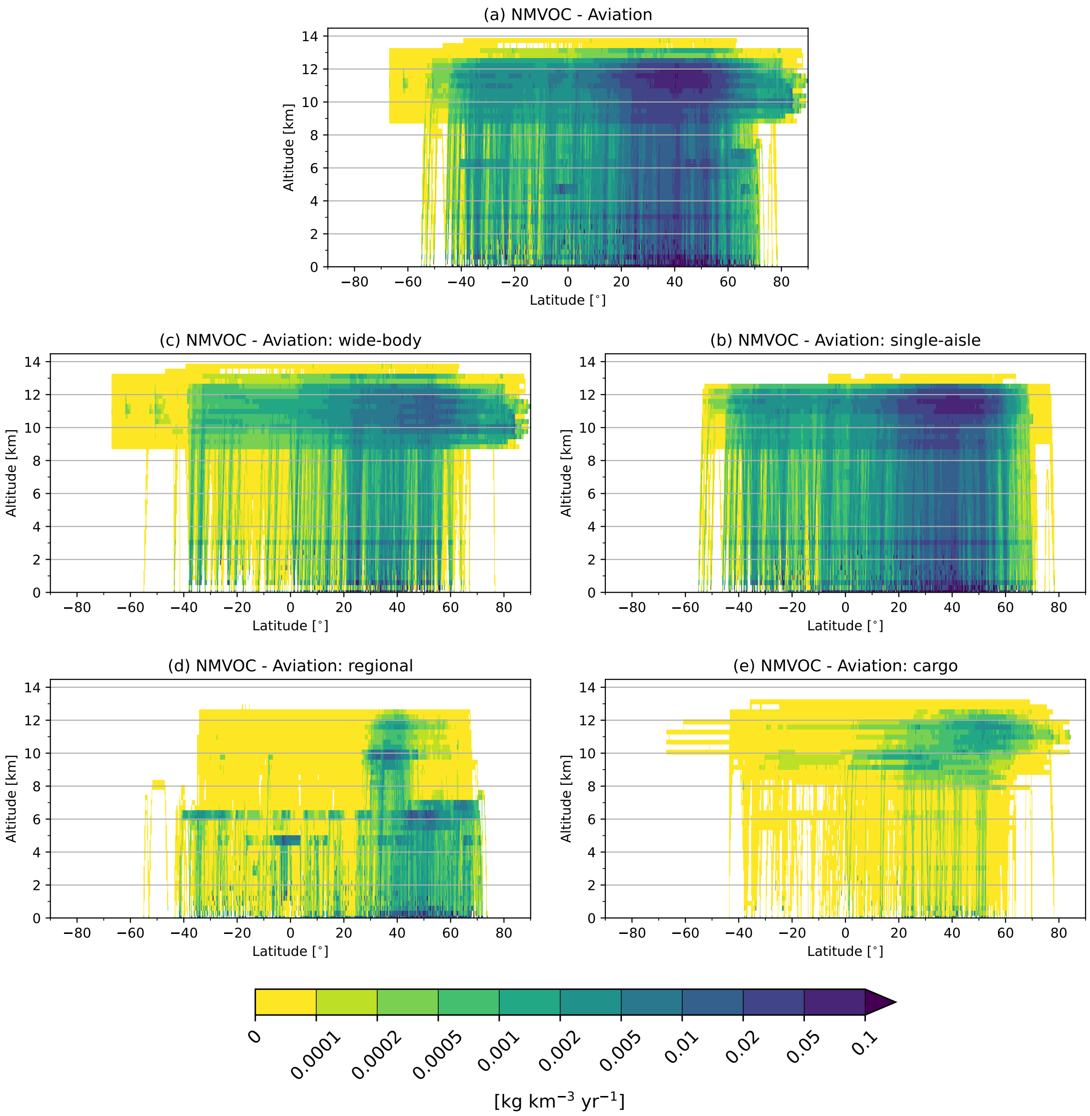


Figure S62: Zonally averaged NMVOC emissions from aviation.

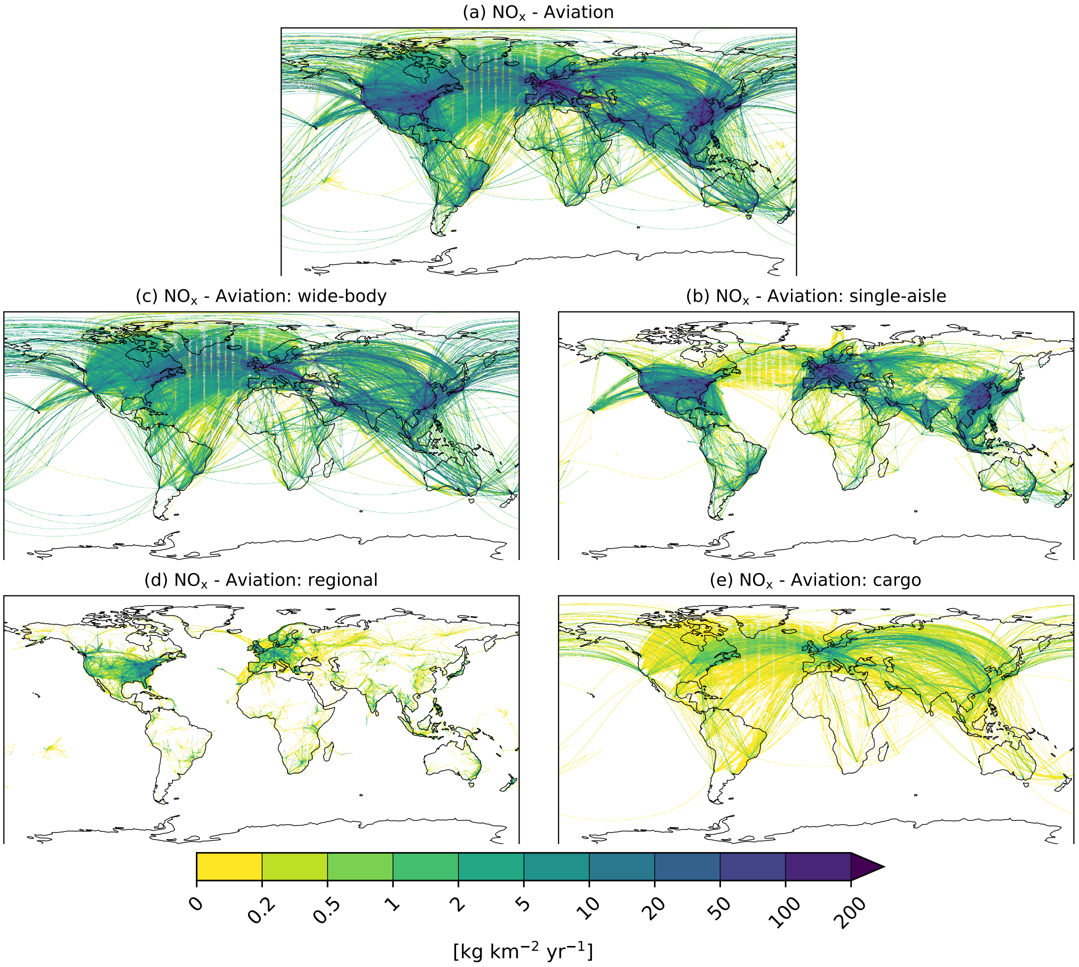


Figure S63: Vertically integrated NO_x emissions from aviation.

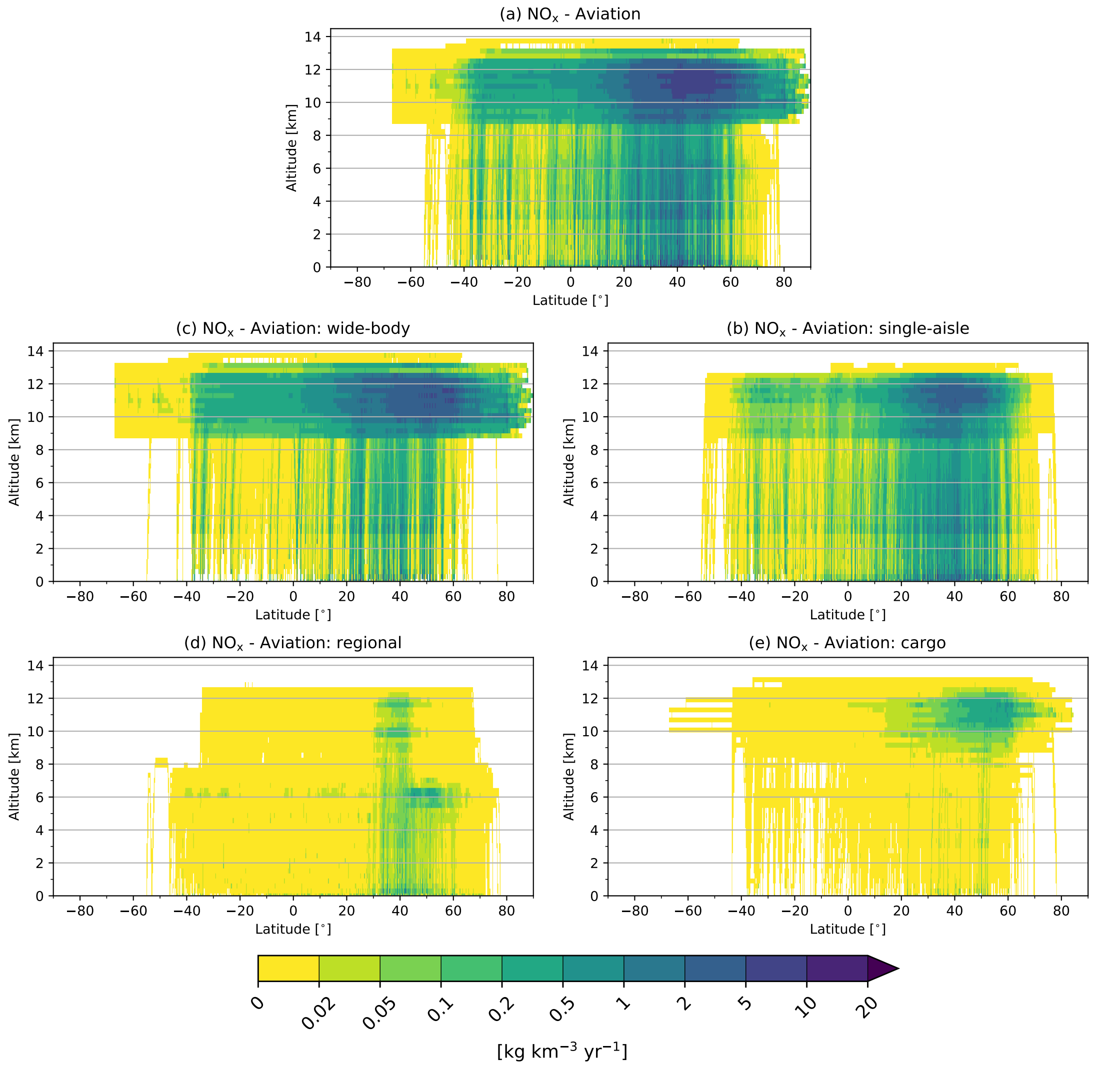


Figure S64: Zonally averaged NO_x emissions from aviation.

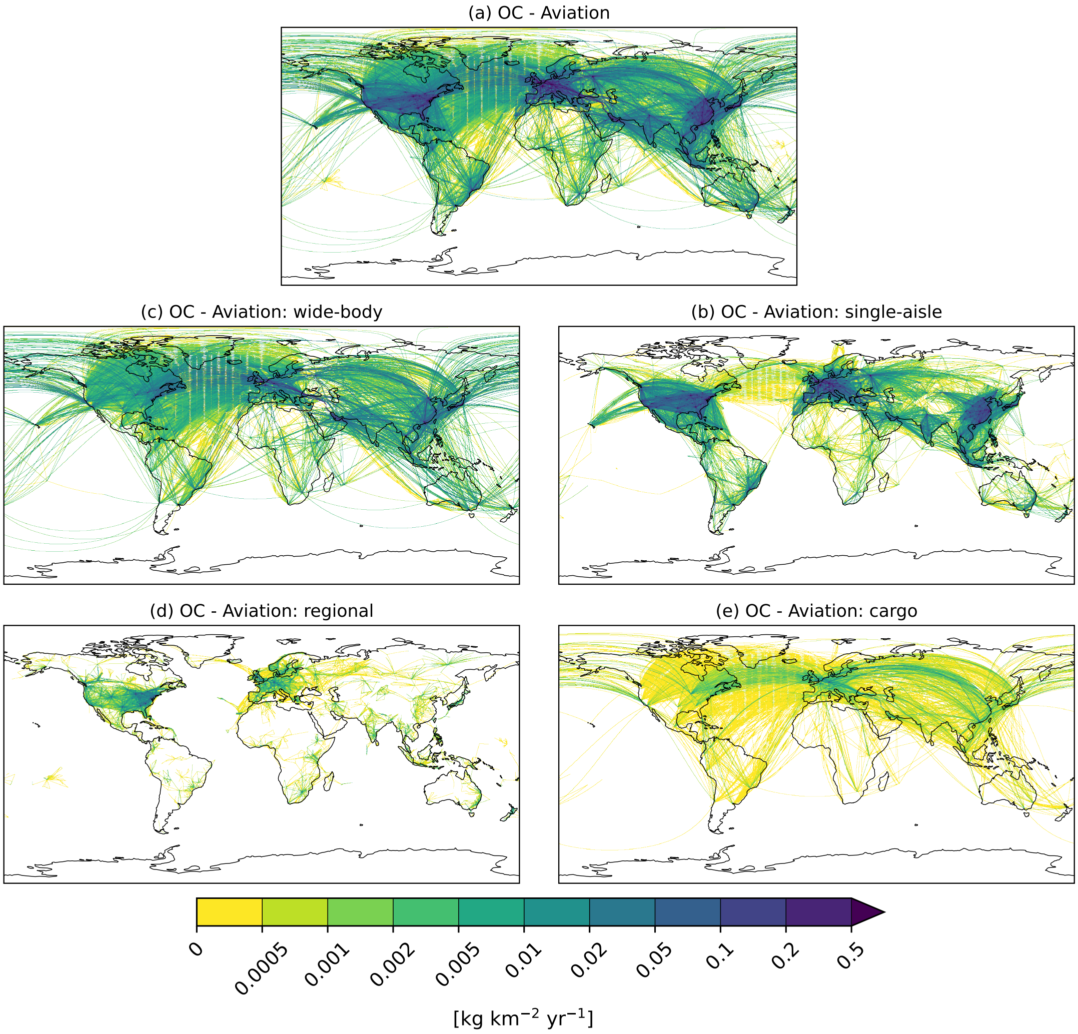


Figure S65: Vertically integrated OC emissions from aviation.

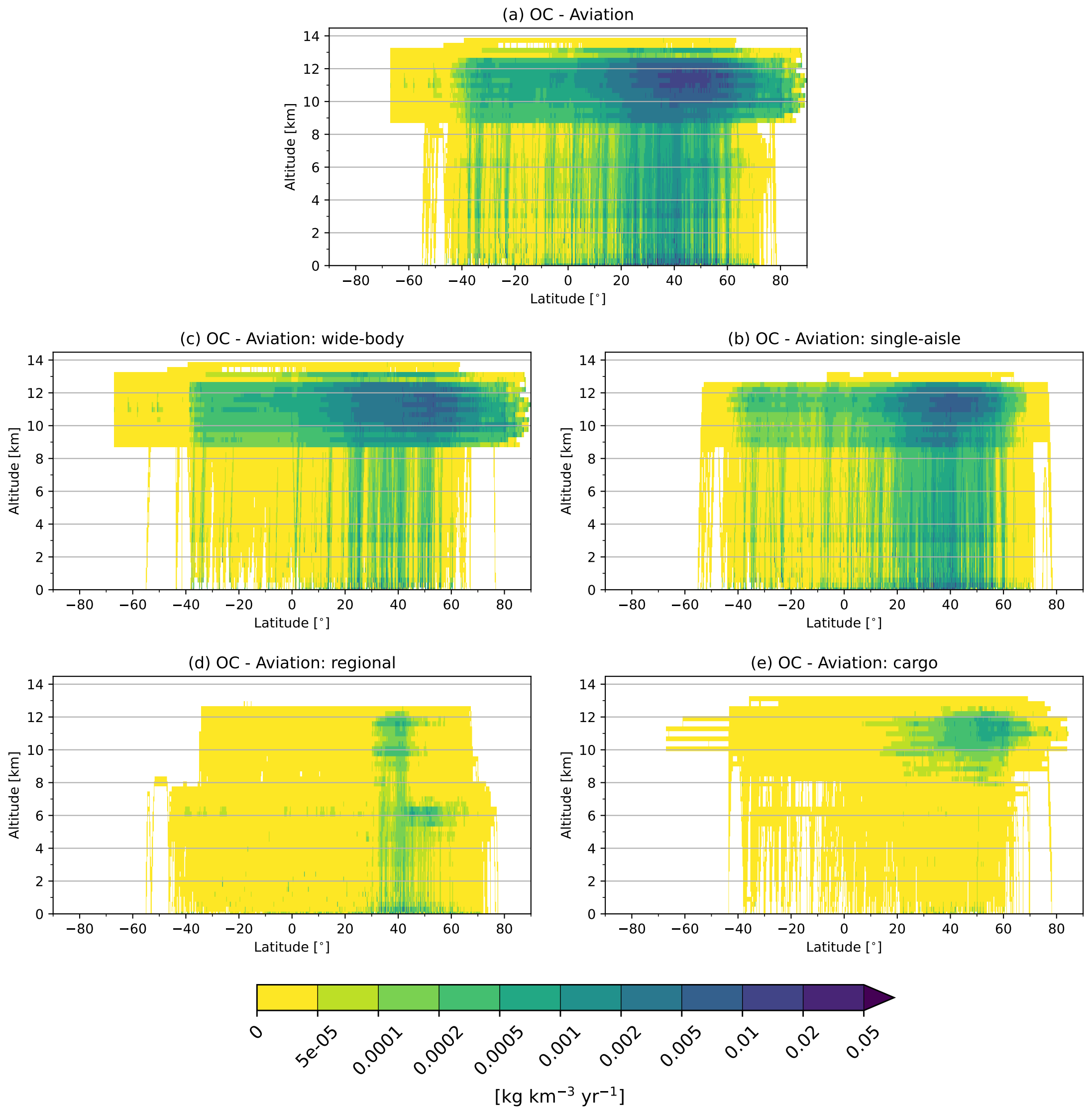


Figure S66: Zonally averaged OC emissions from aviation.

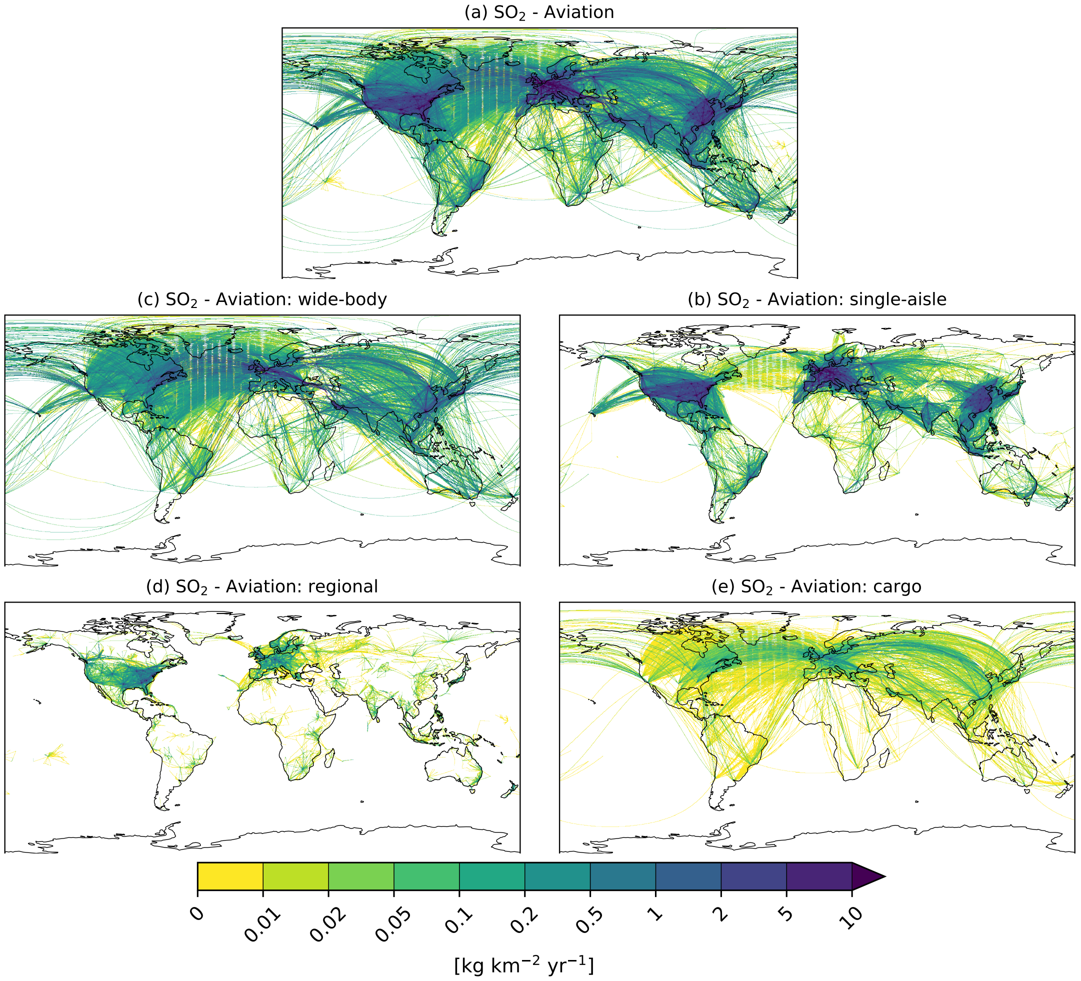


Figure S67: Vertically integrated SO_2 emissions from aviation.

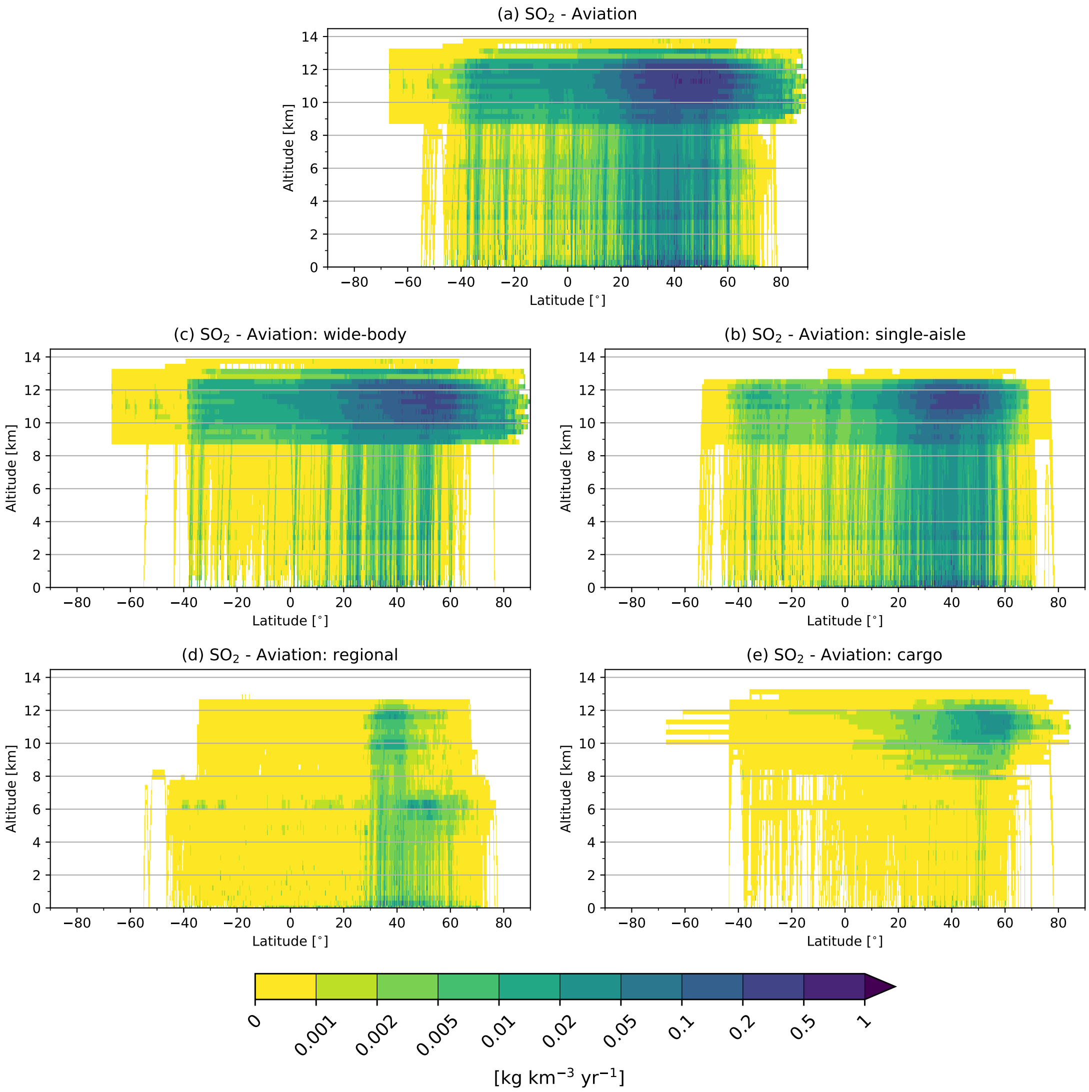


Figure S68: Zonally averaged SO_2 emissions from aviation.

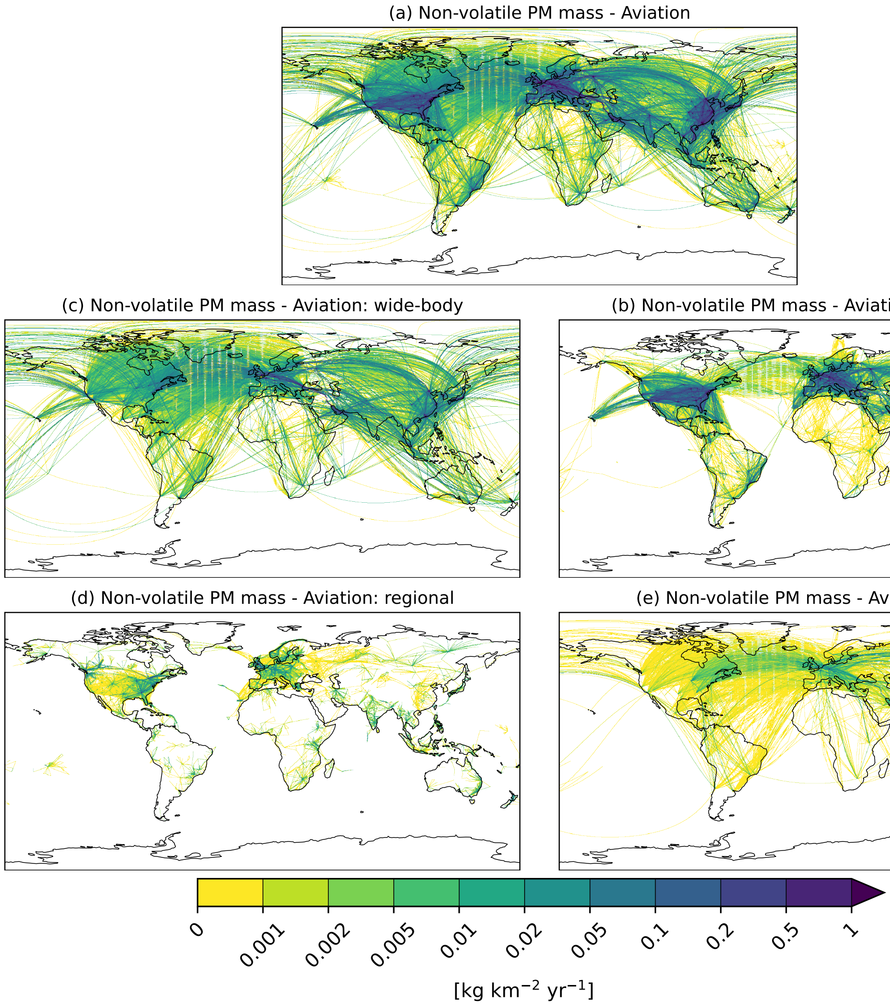


Figure S69: Vertically integrated non-volatile PM mass emissions from aviation.

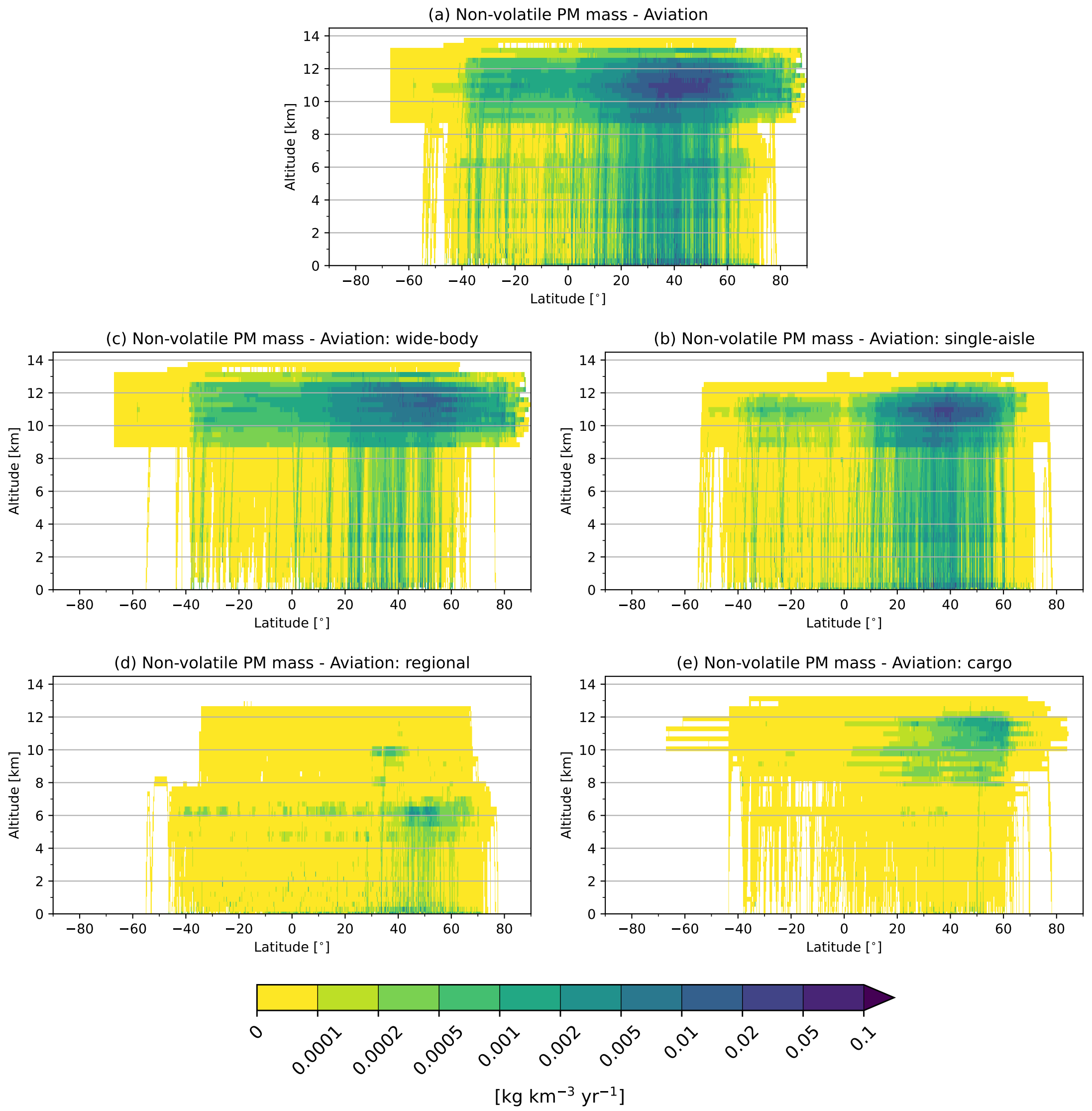


Figure S70: Zonally averaged non-volatile PM mass emissions from aviation.

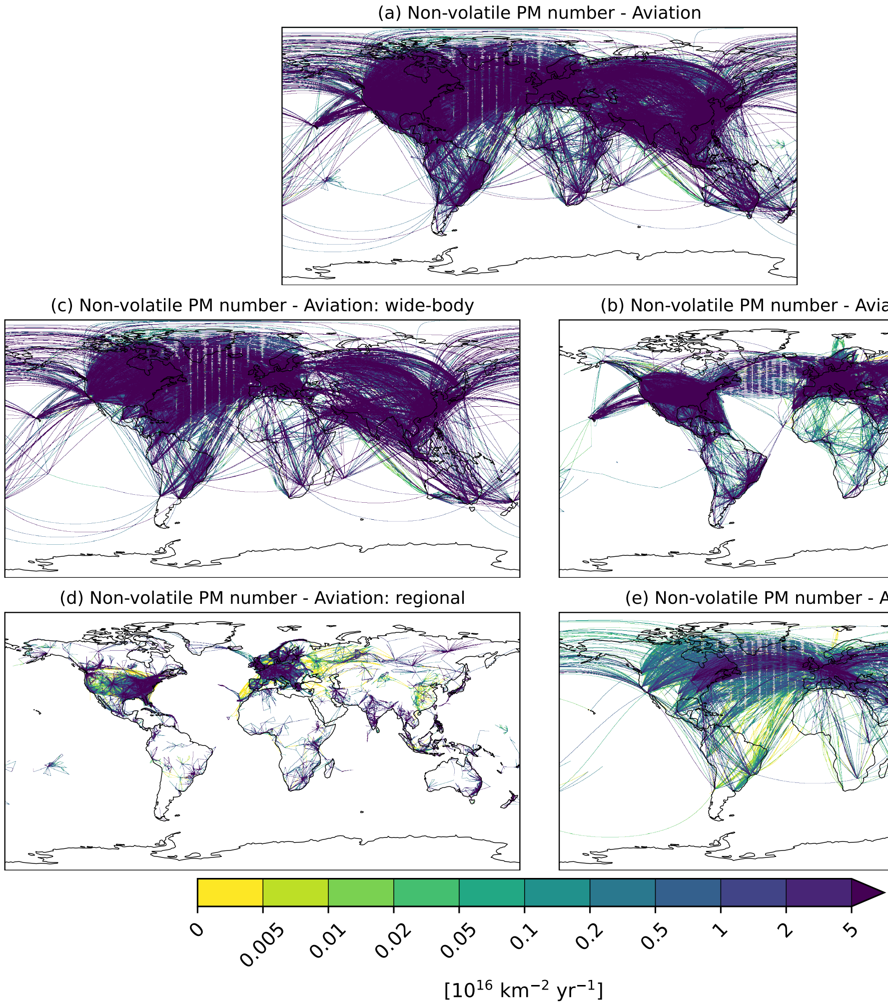


Figure S71: Vertically integrated non-volatile PM number emissions from aviation.

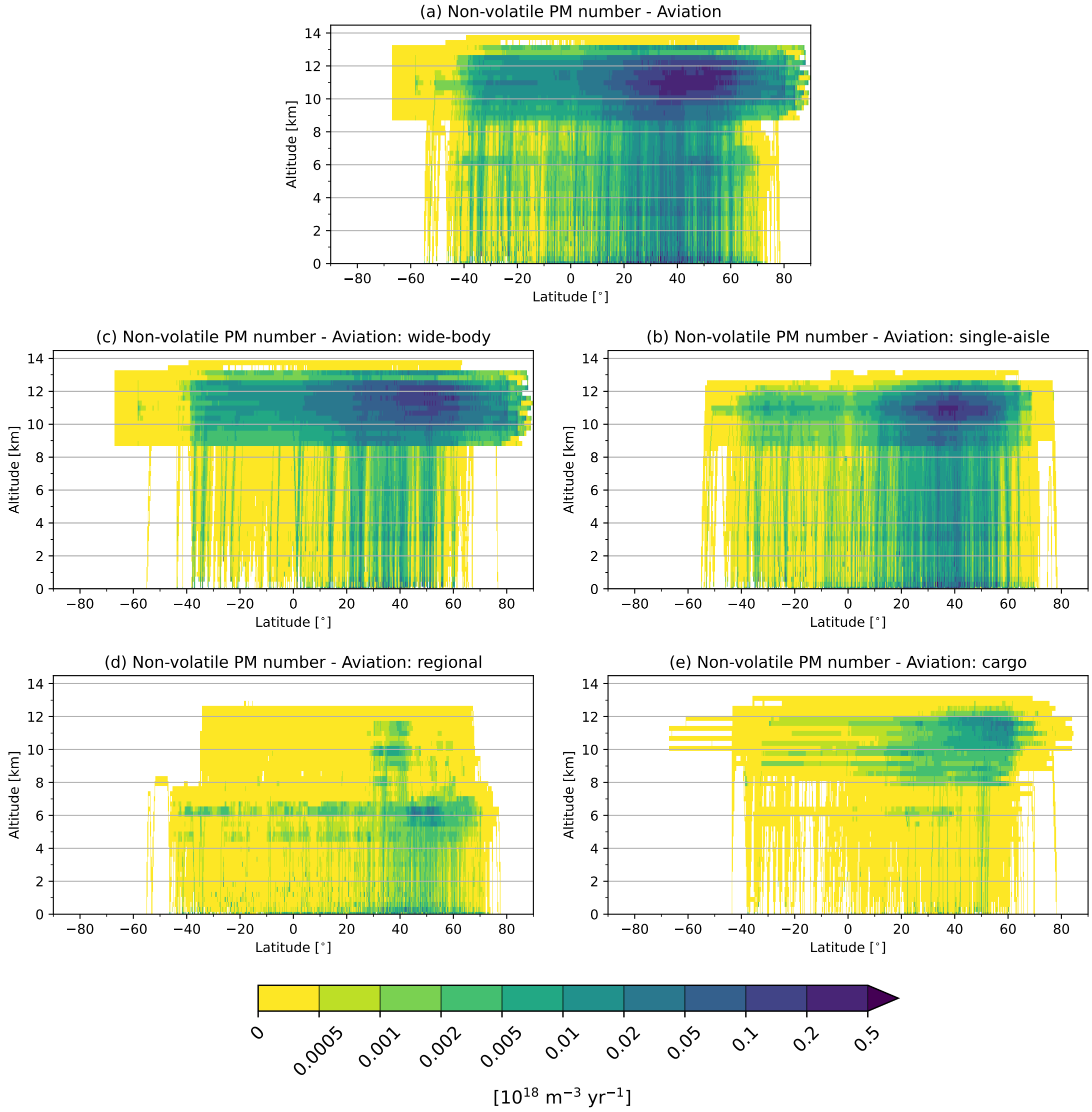


Figure S72: Zonally averaged non-volatile PM number emissions from aviation.

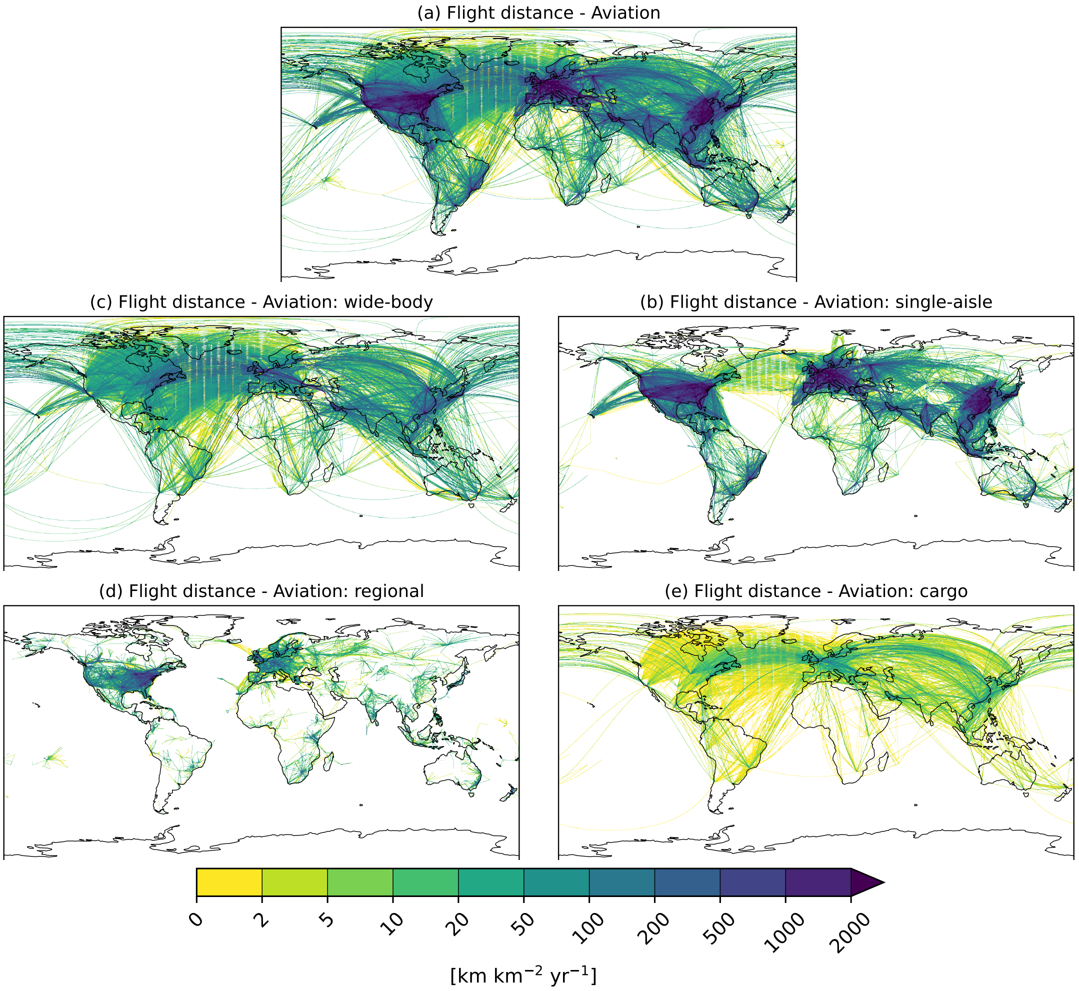


Figure S73: Vertically integrated flight distance.

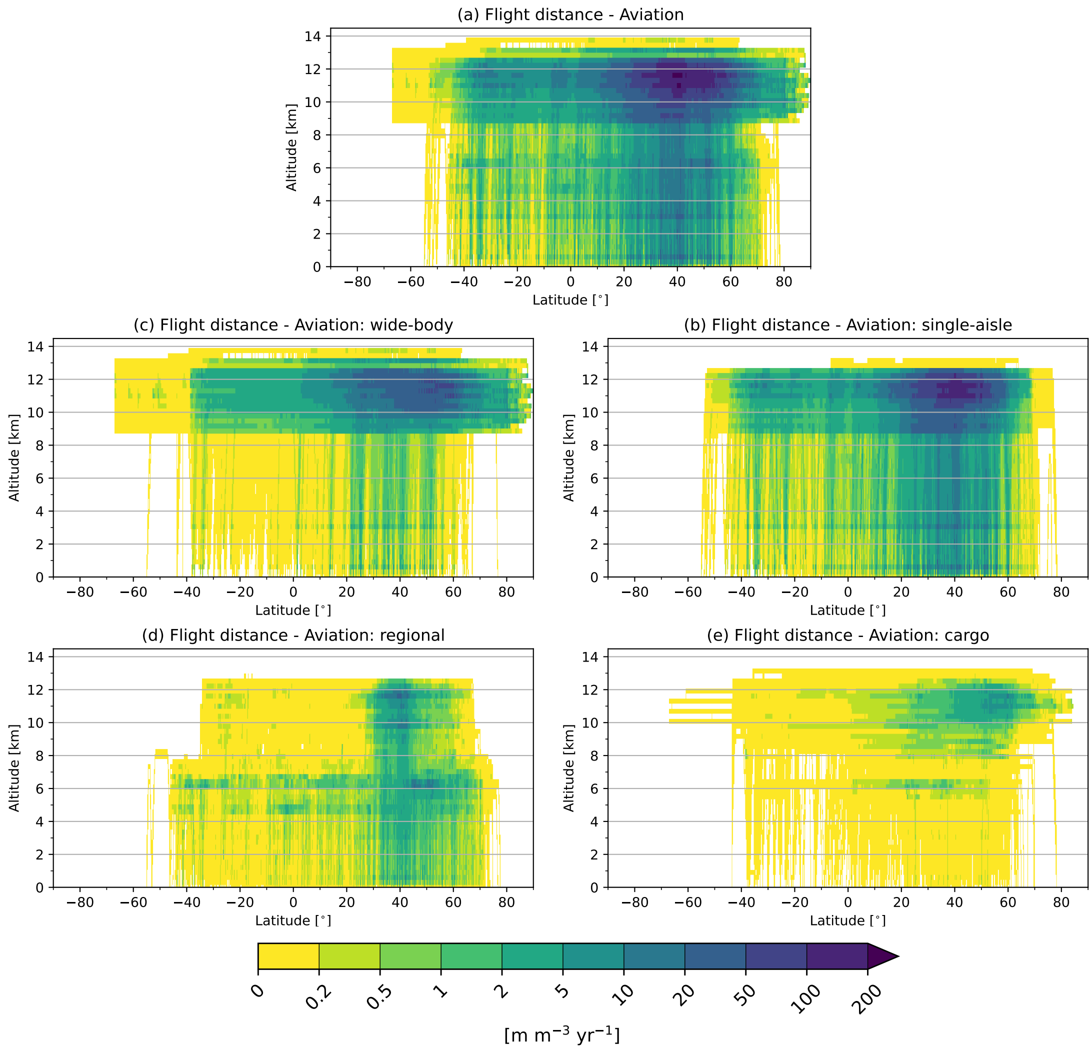


Figure S74: Zonally averaged flight distance.

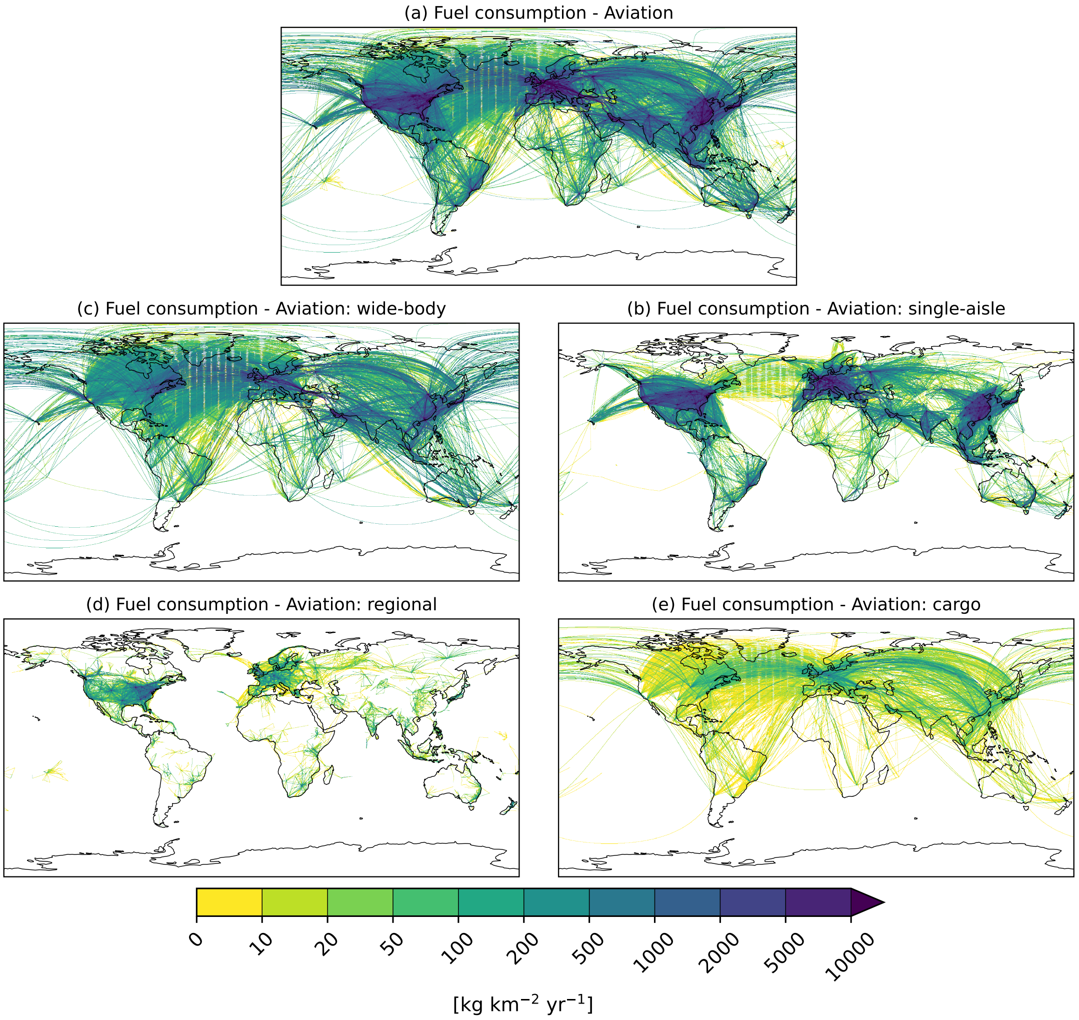


Figure S75: Vertically integrated fuel consumption of aviation.

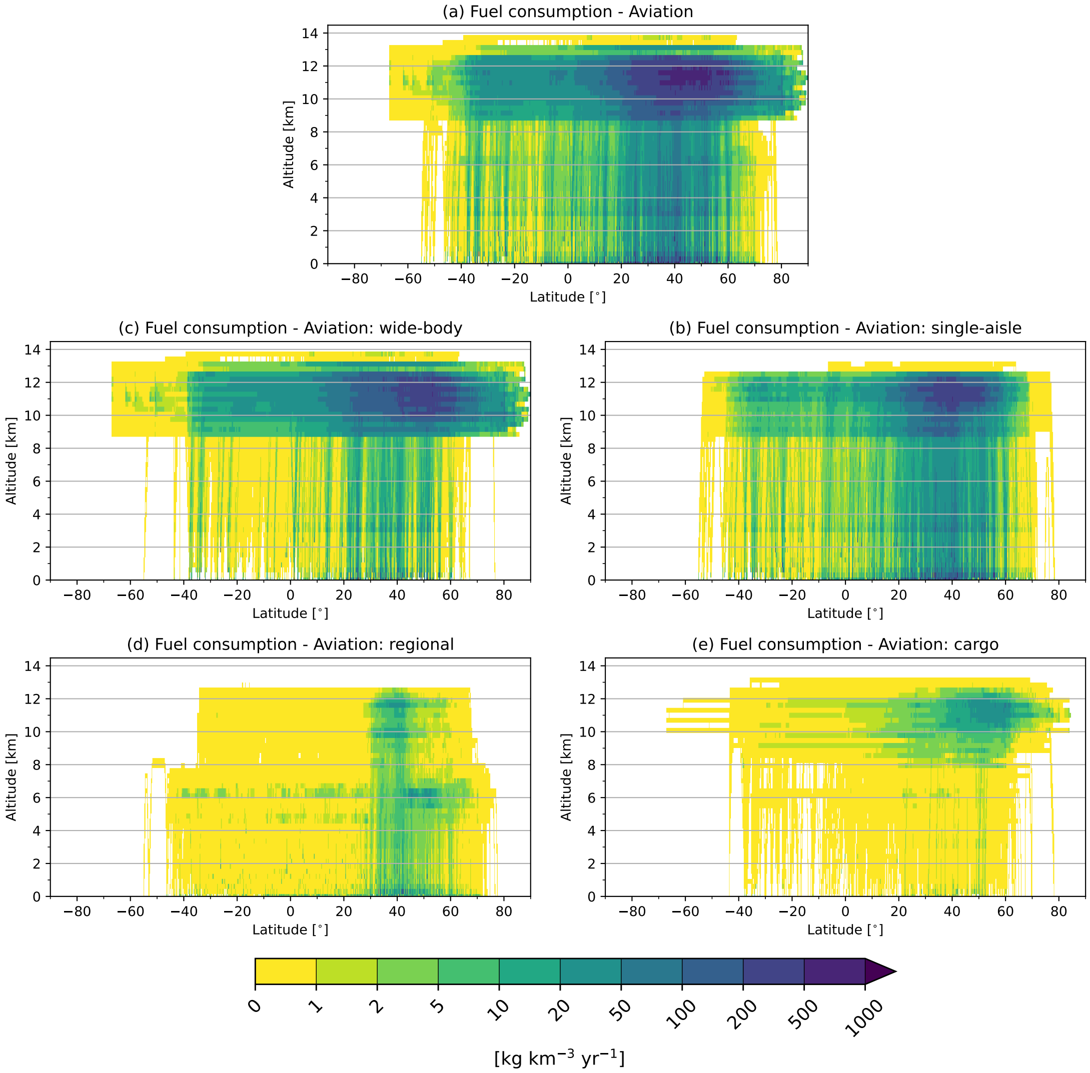


Figure S76: Zonally averaged fuel consumption of aviation.

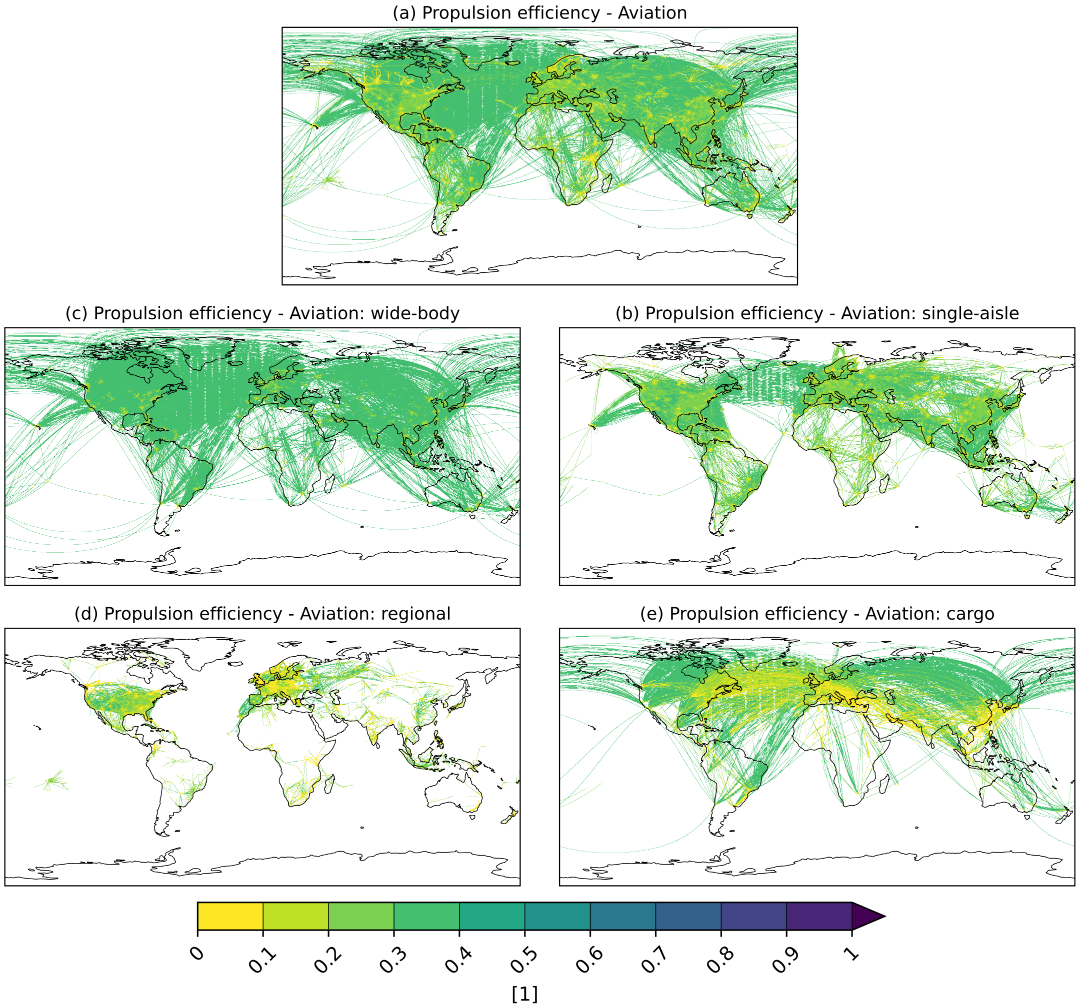


Figure S77: Vertically integrated propulsion efficiency of aviation.

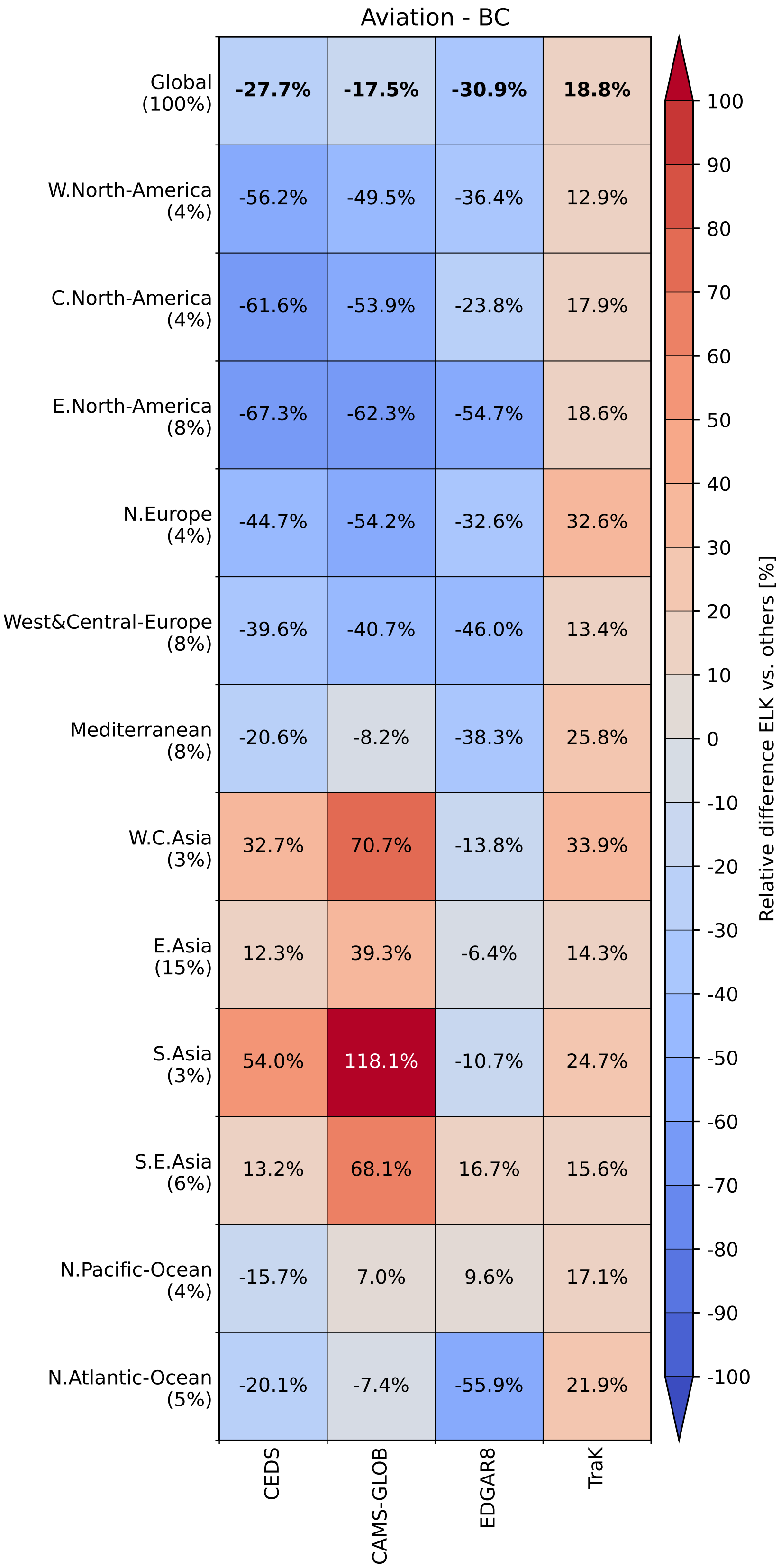


Figure S78: Relative difference of aggregated aviation emissions of BC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

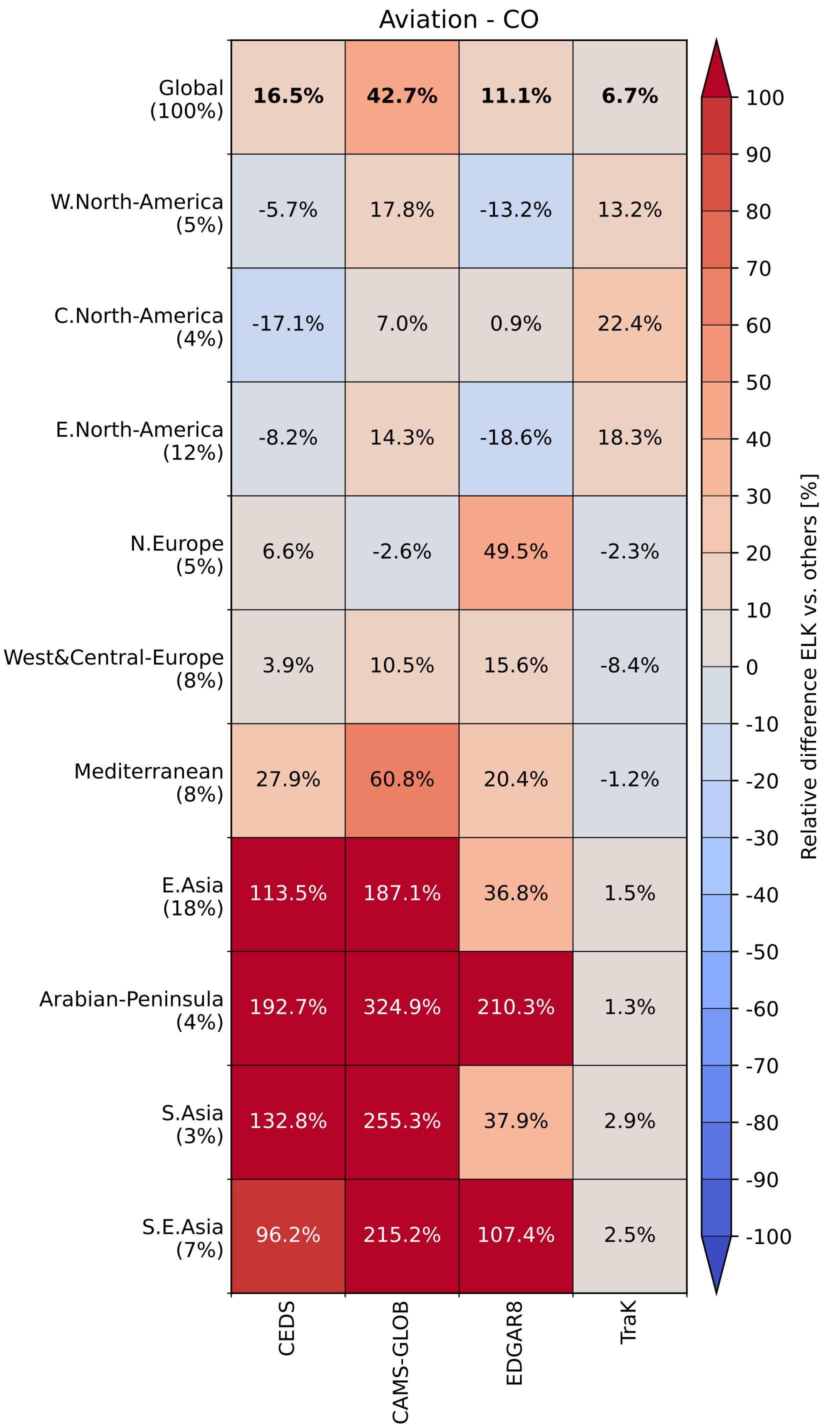


Figure S79: Relative difference of aggregated aviation emissions of CO between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

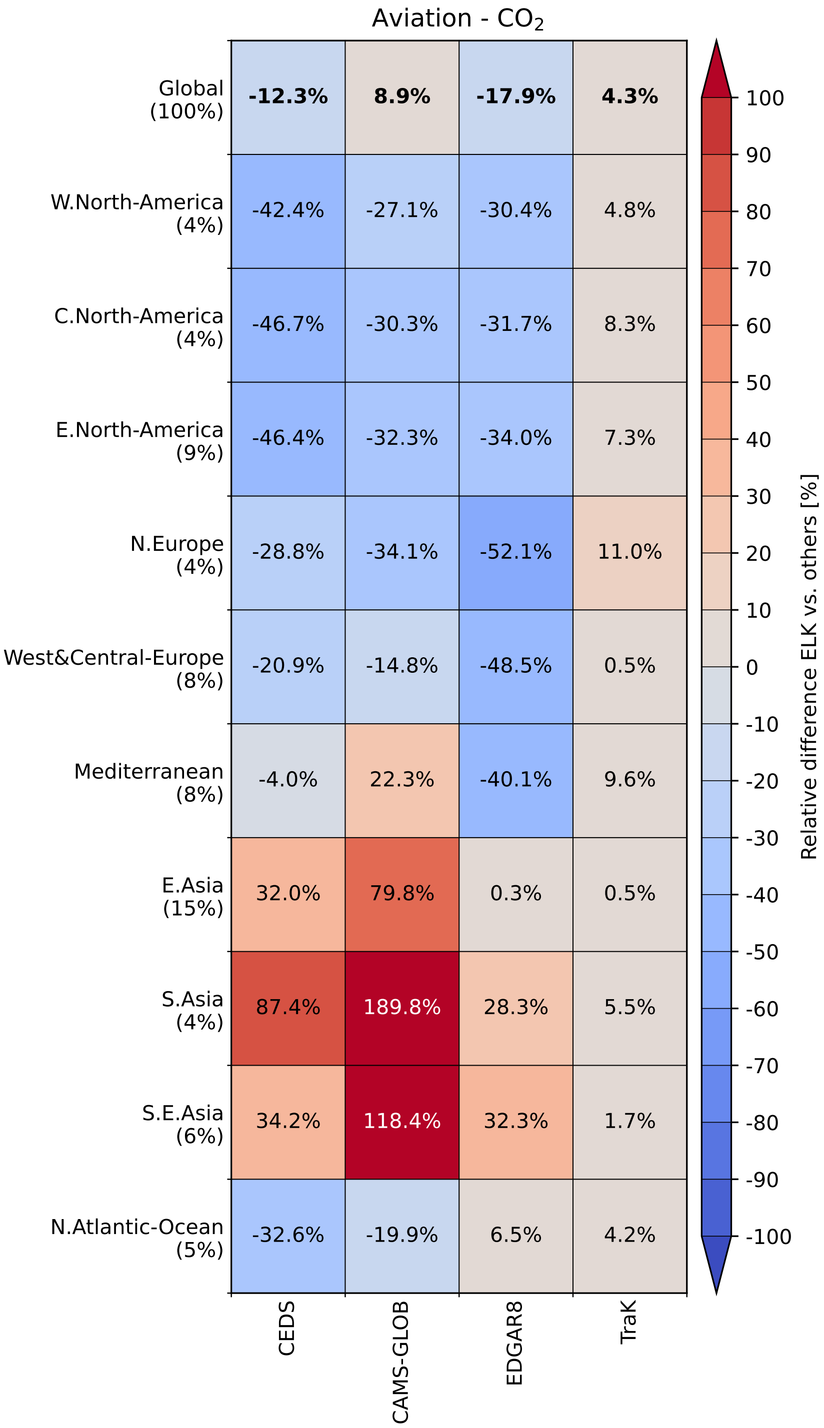


Figure S80: Relative difference of aggregated aviation emissions of CO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

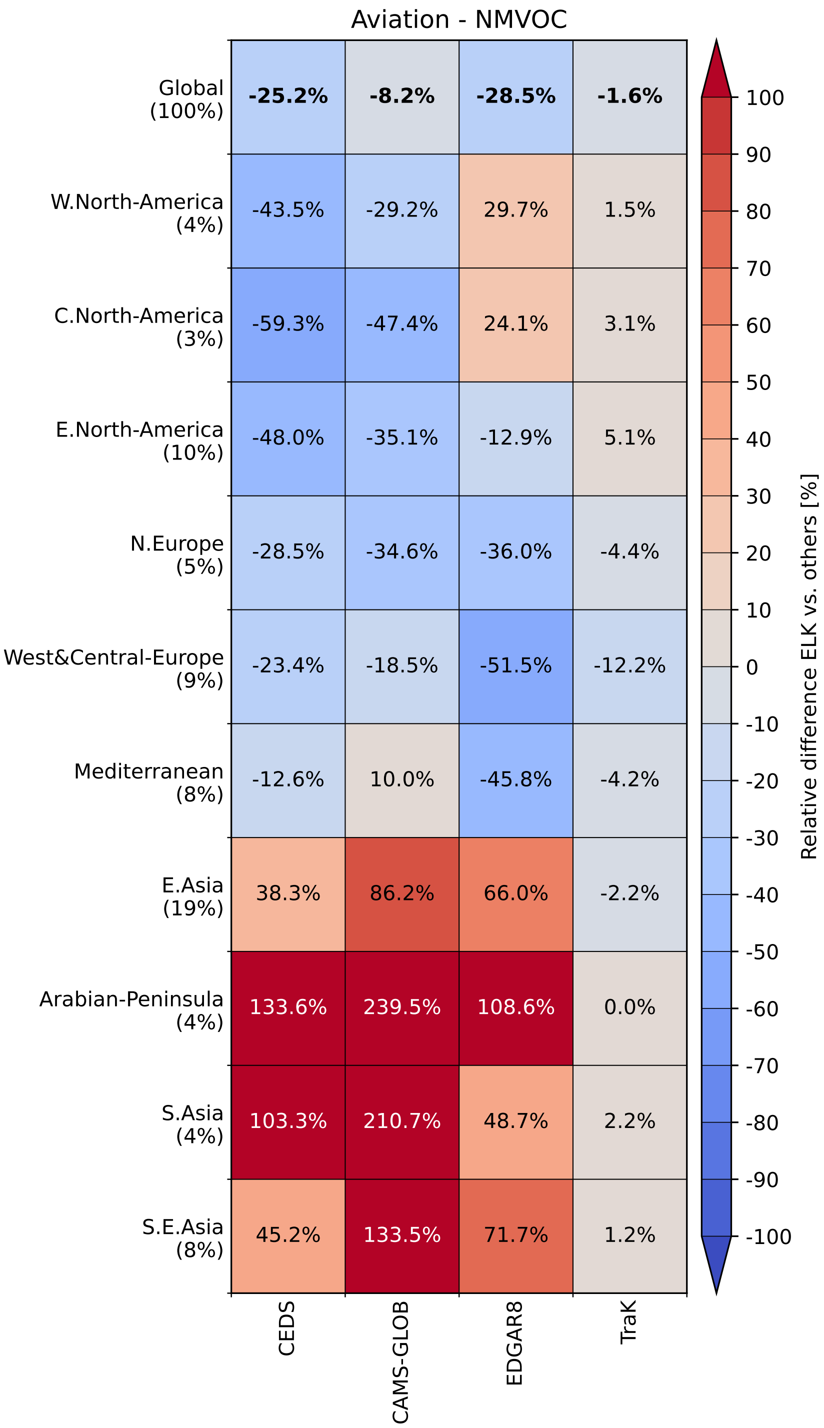


Figure S81: Relative difference of aggregated aviation emissions of NMVOC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

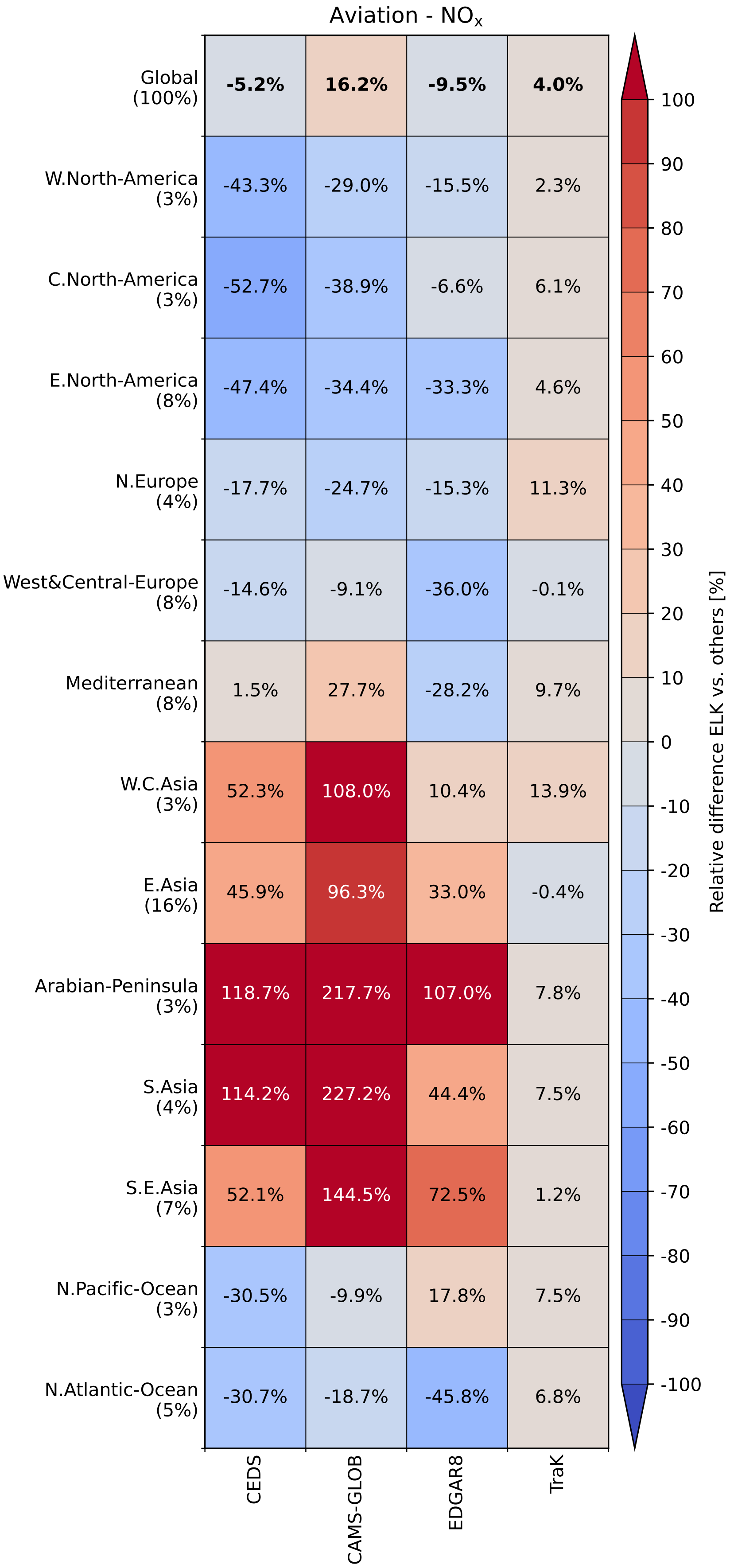


Figure S82: Relative difference of aggregated aviation emissions of NO_x between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

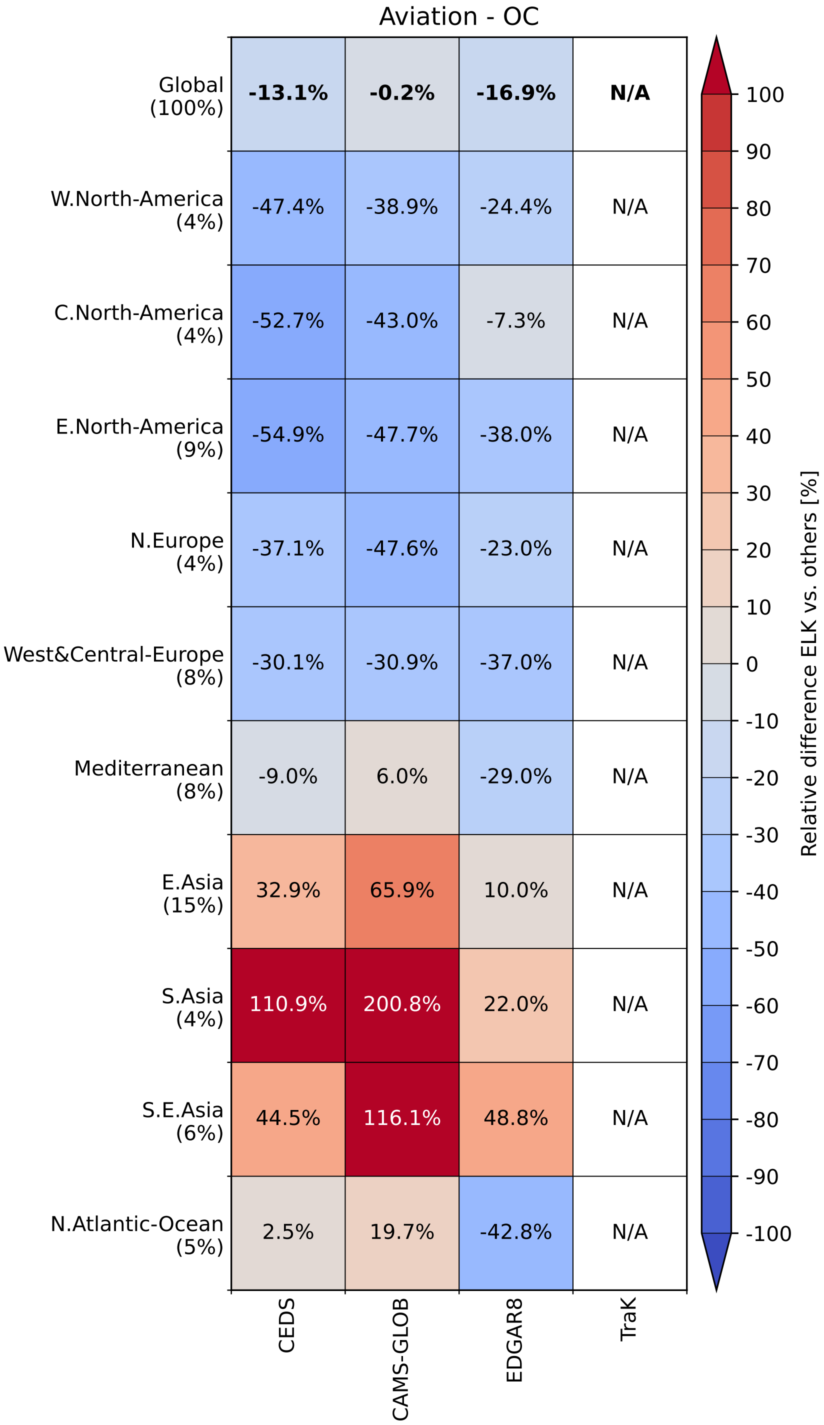


Figure S83: Relative difference of aggregated aviation emissions of OC between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

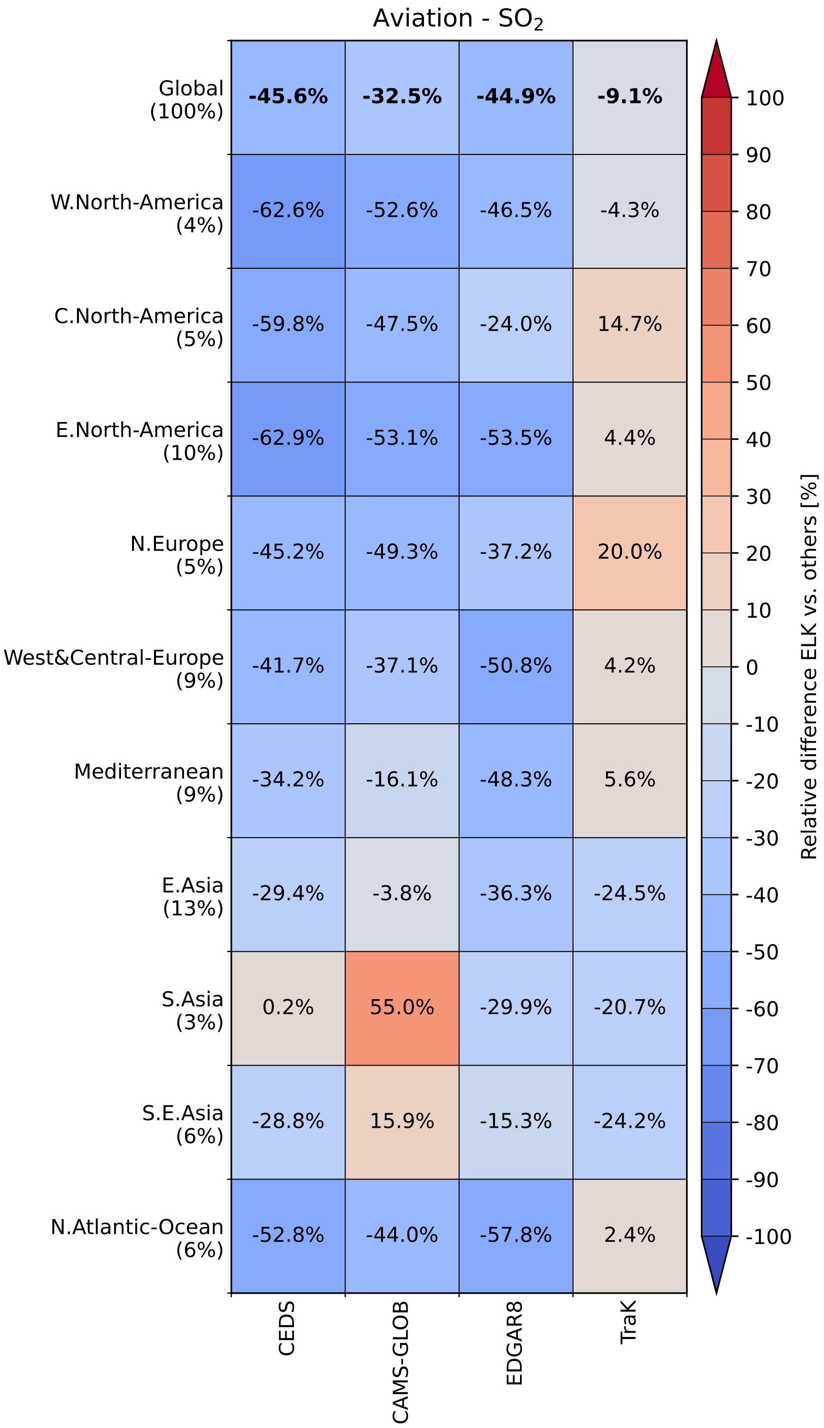


Figure S84: Relative difference of aggregated aviation emissions of SO_2 between ELK and the other global inventories in different world regions. The percent figure below each region name indicates the share of total emissions in that region. Regions comprising less that 3 % of the total are not included in the plot.

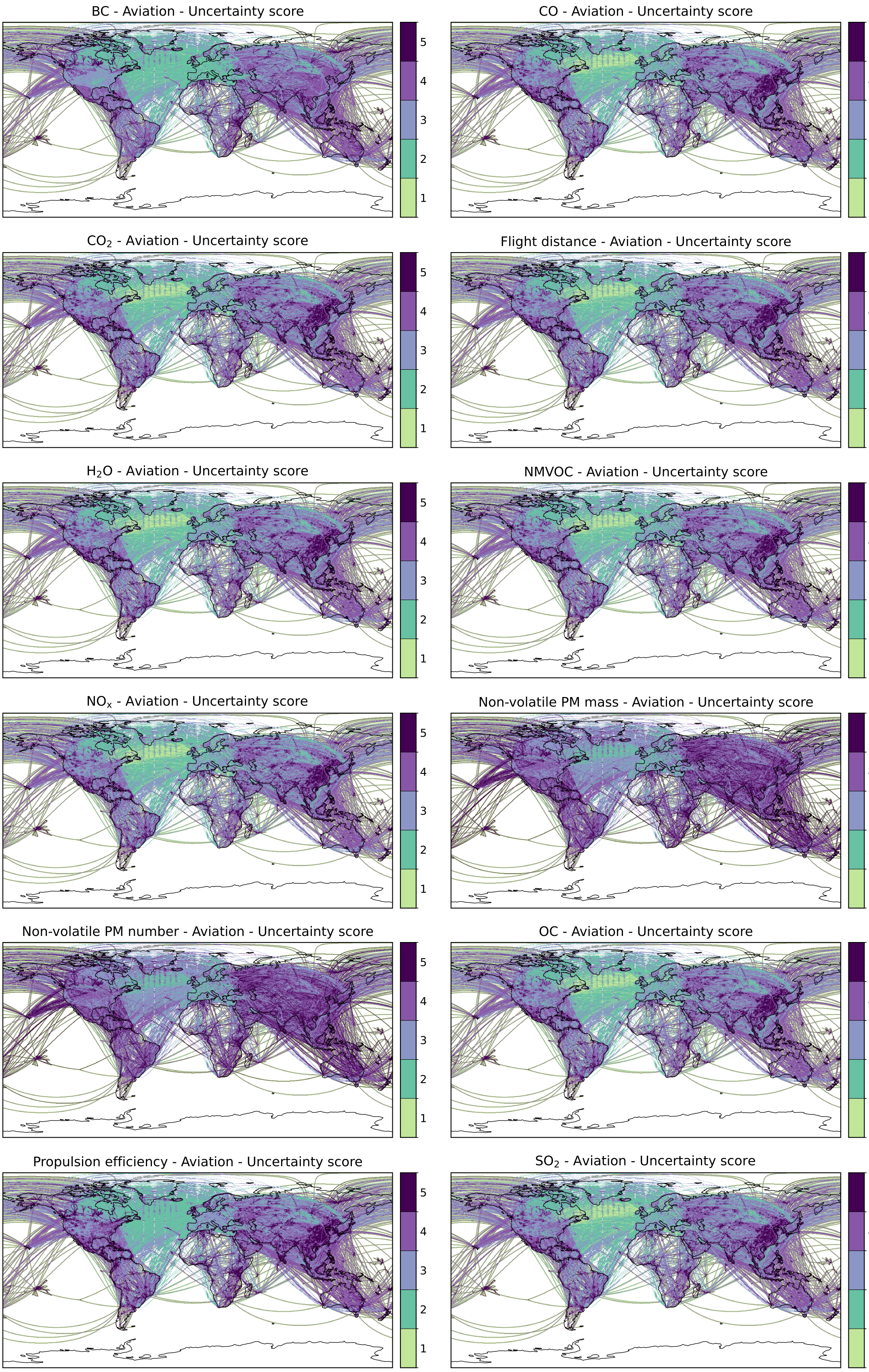


Figure S85: Uncertainty scores for the aviation emissions.

5 Results: Energy for transport

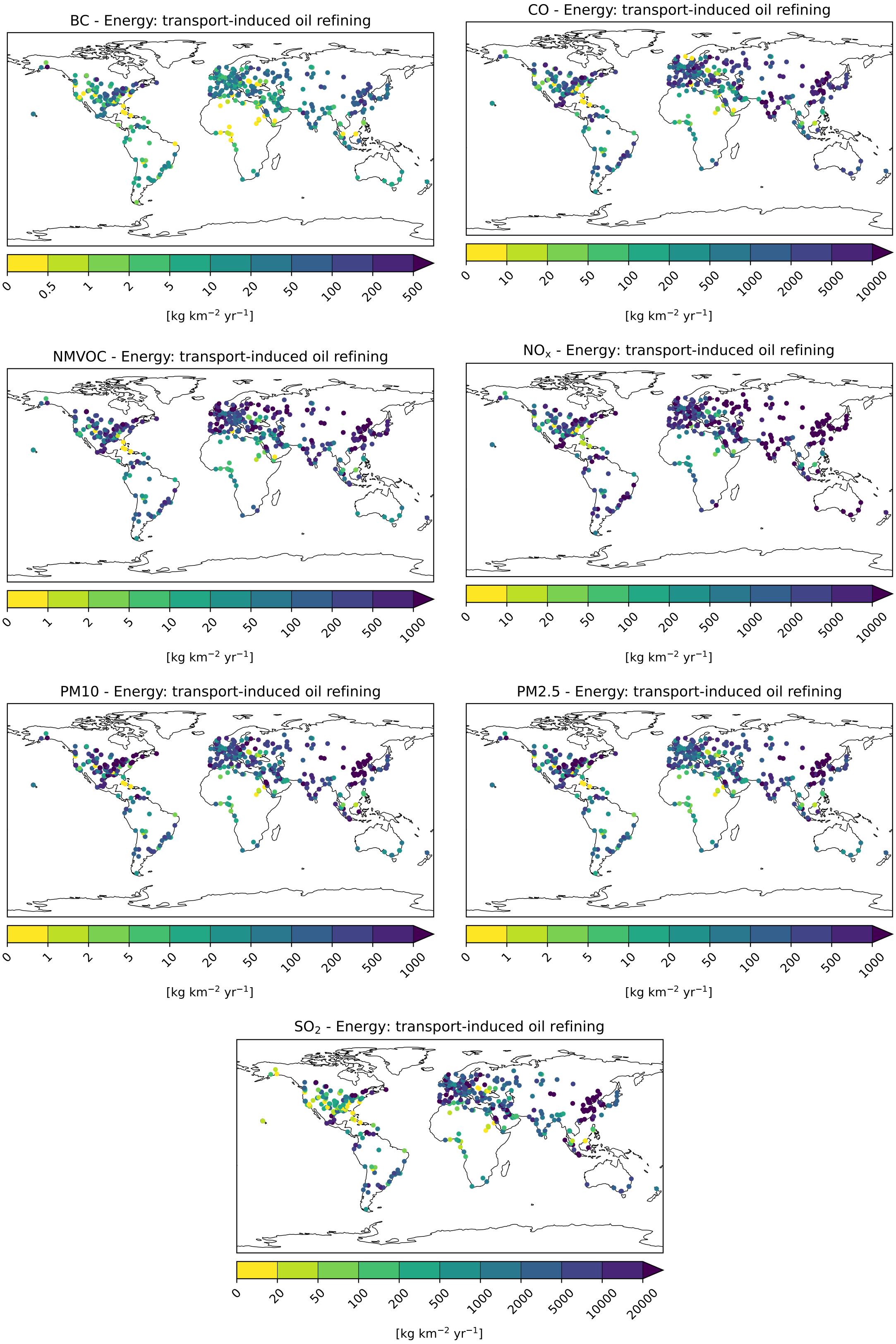


Figure S86: Emissions from energy for transport.

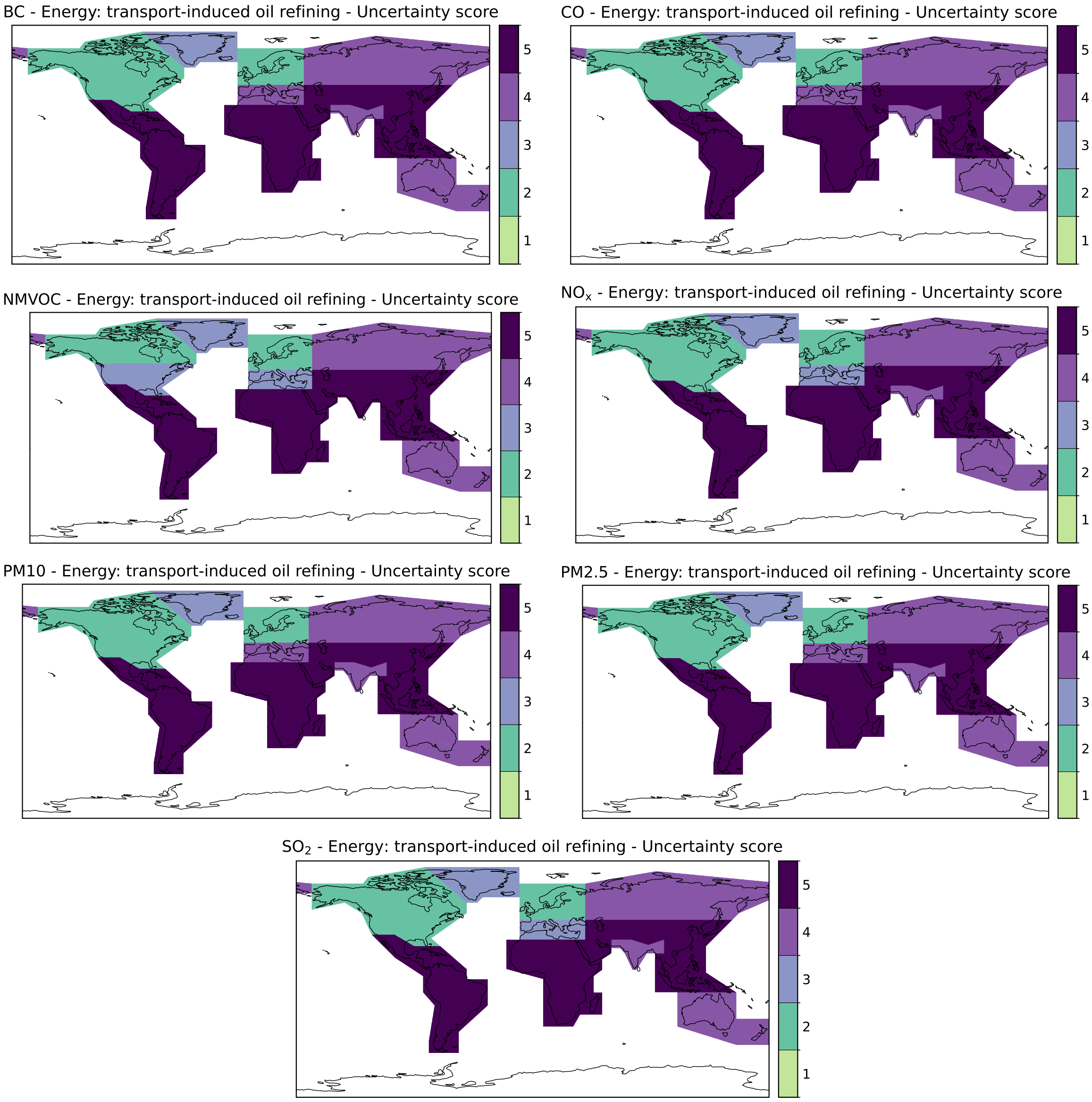


Figure S87: Uncertainty scores for energy for transport emissions.