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SPECIFICATION SHEET: CMV_C3 2016beta Platform

Description: Category 3 Commercial Marine Vessel (cmv_c3) emissions, for simulating 2016 and future year U.S. air quality

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1. Executive Summary

Commercial Marine Vessel (CMV) emissions for ships with Category 3 (i.e., large) engines are modeled in the cmv_c3 sector as point sources. The cmv_c3 sector includes emissions in U.S. state and federal waters, and areas beyond U.S. federal waters. The 2016 beta platform includes projections of cmv_c3 emissions from the 2014 National Emissions Inventory version 2 (NEI2014v2) to 2016, 2023, and 2028. Base and future year inventories were processed with the Sparse Matrix Operating Kernel Environment (SMOKE) v4.6. National and state-level emission summaries for key pollutants are provided.

2. INTRODUCTION

This document details the approach and data sources used for developing 2016, 2023, and 2028 emissions for the Commercial Marine Vessel, Category 3 (cmv_c3) sector. The 2016 beta platform cmv_c3 inventory is projected to 2016 from the U.S. EPA NEI2014v2[1] nonpoint inventory, and then converted to a point inventory format to support simulating plume rise for these sources.

The cmv_c3 sector contains large engine CMV emissions. Category 3 (C3) marine diesel engines are those at or above 30 liters per cylinder, typically these are the largest engines rated at 3,000 to 100,000 hp. C3 engines are typically used for propulsion on ocean-going vessels including container ships, oil tankers, bulk carriers, and cruise ships. Emissions control technologies for C3 CMV sources are limited due to the nature of the residual fuel used by these vessels.[2] The cmv_c3 sector contains sources that traverse state and federal waters and that are in the NEI2014v2; plus sources in waters not covered by the NEI. Where the Category 3 CMV (cmv_c3) inventory is modeled as point sources with plume rise, the cmv_c1c2 sources are modeled as area sources with emissions that occur only near the Earth's surface.

The cmv_c3 sources that operate outside of state waters but within the federal Emissions Control Area (ECA) are encoded with a Federal Information Processing Standard (FIPS) state code of 85. The ECA areas include parts of the Gulf of Mexico, and parts of the Atlantic and Pacific coasts. As the U.S. federal waters around Puerto Rico and Alaska are outside the continental U.S. (CONUS) modeling domain, cmv_c3 sources for these regions are not included in the 2016beta inventory. The cmv_c3 sources in the 2016beta inventory are categorized as operating either in-port or underway and are encoded using the two source classification codes (SCCs) listed in Table 1. In addition to C3 sources in state and federal waters, the cmv_c3 sector includes emissions in waters not covered by the NEI (FIPS = 98) and taken from the "ECA-IMO-based" C3 CMV inventory[3]. The ECA-IMO inventory is also used for allocating the county-level emissions to geographic locations.

[1] https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data
[2] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-marine-vessels
[3] https://www.epa.gov/sites/production/files/2017-08/documents/2014v7.0_2014_emismod_tsdv1.pdf

Table 1. 2016 beta platform SCCs for cmv_c3 sector

SCC	Tier 1 Description	Tier 2 Description	Tier 3 Description	Tier 4 Description
2280003100	Mobile Sources	Marine Vessels, Commercial	Residual	Port emissions
2280003200	Mobile Sources	Marine Vessels, Commercial	Residual	Underway emissions

3. Inventory Development Methods

Development of the 2016 beta platform cmv_c3 inventory consisted of two steps: converting the NEI2014v2 nonpoint C3 emissions to point format, and projecting those emissions to year 2016. These steps are described below.

Conversion of NEI2014v2 nonpoint C3 to point format

The NEI2014v2 nonpoint C3 inventory was converted to a point inventory to support plume rise calculations for C3 vessels. The nonpoint emissions were allocated to point sources using a multi-step allocation process because not all of the inventory components had a complete set of county-SCC combinations. In the first step, the county-SCC sources from the nonpoint file were matched to the county-SCC points in the 2011 ECA-IMO C3 inventory. The ECA-IMO inventory contains multiple point locations for each county-SCC. The nonpoint emissions were allocated to those points using the $PM_{2.5}$ emissions at each point as a weighting factor.

The cmv_c3 port emissions, which did not have a matching FIPS in the ECA-IMO inventory, were allocated using the 2016 port shapefiles obtained from the EPA Office of Transportation and Air Quality (OTAQ). The contribution fraction of $PM_{2.5}$ from each county that overlapped with the port area polygon was calculated as an initial weighting factor. The port polygons were then drawn with an overlapping 4 km resolution modeling grid on a Lambert Conformal Conic projection. The fraction of the area of each grid cell overlapping the port polygon was calculated as a second weighting factor. The centroids of the grid cells overlapping each port was obtained and grouped by county FIPS. A final area-to-point allocation factor was calculated using the product of the two weighting factors at each centroid point and normalizing the sum of all weighting factors in a county to unity. Any remaining unmatched counties with port emissions from the area inventory were allocated to the centroids of the cells in the 12 km 2014 port area spatial surrogate (surrogate code 801). The emissions for those counties were allocated using the weighting factors in the surrogate.

The cmv_c3 underway emissions that did not have a matching FIPS in the ECA-IMO inventory were allocated using the 12 km 2014 offshore shipping activity spatial surrogate (surrogate code 806). Each county with underway emissions in the area inventory was allocated to the centroids of the cells associated with the respective county in the surrogate. The emissions were allocated using the weighting factors in the surrogate.

The resulting point emissions were converted to an annual point 2010 flat file format (FF10). A set of standard stack parameters were assigned to each release point in the cmv_c3 inventory. The assigned stack height was 65.62 ft, the stack diameter was 2.625 ft, the stack temperature was 539.6 °F, and the velocity was 82.02 ft/s.

Projection of NEI2014v2 point C3 to 2016

Projections of the NEI2014v2 cmv_c3 emissions to the year 2016 were based on United States Army Corps of Engineers' Entrance and Clearance (E&C) data. Those data were used to estimate the change in commercial shipping activity between 2014 and 2016. E&C data includes records of each entrance and clearance of a port by any vessel involved in international commerce annually. The data do not include information for Jones Act Ships, which are U.S.-owned and U.S.-crewed ships that transit exclusively between U.S. ports. E&C data from 2014 and 2015 were used to determine C3 marine vessel trips by region, engine type, and year built.

In 2014, marine vessels in the North American Emission Control Area (ECA), which extends 200 miles from the shores of North America, Puerto Rico, and the Virgin Islands, met a fuel sulfur standard of 10,000 ppm. On January 1st, 2015, the ECA initiated a fuel sulfur standard which regulated large marine vessels to use fuel with 1,000 ppm sulfur or less. EPA multiplied European Union (EU)[4] C3 emissions factors that include these standards with the E&C calls of the respective years.

The EU emission factors also reflect IMO Tier 3 NOx regulations that apply to engines installed on ships constructed (i.e., keel is laid) on or after January 1st, 2016. However, in allotting time for ship building and engine installation, EPA does not expect Tier 3 vessels to be active by December 31st, 2016. Therefore, the 2016 regional fleet population was assumed to be the same as that of 2015, and the appropriate emission factors were applied. The final growth factors were determined by dividing the 2016 sum of the products of emission factors and calls by that of 2014 per pollutant and region.

The cmv_c3 projection factors are pollutant-specific and region-specific. Most states are mapped to a single region with a few exceptions. Pennsylvania and New York were split

[4] http://ec.europa.eu/environment/air/pdf/chapter1_ship_emissions.pdf

between the East Coast and Great Lakes, Florida was split between the Gulf Coast and East Coast, and Alaska was split between Alaska East and Alaska West. The 2014-to-2016 projection factors for C3 sources are listed in Table 2. The Non-Federal factors listed in this table were applied to sources outside of U.S. federal waters (FIPS 98). Volatile Organic Compound (VOC) Hazardous Air Pollutant (HAP) emissions were projected using the VOC factors. NH3 emissions were held constant at 2014 levels.

Table 2. 2014-to-2016 projection factors for C3 CMV

Region	CO	NOX	PM10	PM2.5	SO2	VOC
Alaska East	-3.67%	-4.28%	-61.02%	-61.93%	-90.42%	-3.72%
Alaska West	17.56%	14.49%	-50.95%	-52.83%	-88.38%	17.42%
East Coast	-0.08%	-0.86%	-58.47%	-59.97%	-90.11%	-0.17%
Gulf Coast	-0.03%	-0.96%	-58.04%	-59.68%	-90.06%	-0.04%
Great Lakes	-4.56%	-4.93%	-60.22%	-61.46%	-90.37%	-4.33%
Hawaii East	-5.95%	-6.44%	-61.37%	-62.62%	-90.73%	-6.12%
North Pacific	-8.32%	-9.18%	-61.42%	-62.94%	-90.87%	-8.31%
Puerto Rico	-0.63%	-1.07%	-58.68%	-59.99%	-90.02%	-0.48%
South Pacific	-10.36%	-11.57%	-62.17%	-63.68%	-91.05%	-10.31%
Virgin Islands	-20.01%	-19.80%	-66.57%	-67.49%	-91.80%	-19.59%
Non-Federal	5.98%	5.98%	5.98%	5.98%	5.98%	5.98%

4. ANCILLARY DATA

Spatial Allocation

The 2016beta platform cmv_c3 emissions are point sources and are allocated directly to grid cells within SMOKE. Details regarding the conversion of the area source NEI2014v2 cmv_c3 inventory to the 2016beta platform point source format are available in Section 3 of this document.

Temporal Allocation

Month-of-year temporalization for emissions in the Great Lakes used 2014-based monthly profiles provided by LADCO. For the rest of the sector, month-of-year temporalization used a monthly temporal profile that was first developed for C3 emissions for an earlier EPA emissions modeling platform. As the day-of-week and hour-of-day temporal profiles are flat for all cmv_c3 sources, air quality model-ready emissions were only prepared for one representative day per month. Table 3 lists the annual total 2016 emissions assigned to different monthly temporal profiles. The Great Lakes vessels use the profiles that include “GLCMV” in the monthly profile name; the rest of the cmv_c3 sources used profile "19531". Figure 1 is a plot of the Great Lakes monthly temporal profiles used for the 2016beta emissions.

Table 3. 2016 cmv_c3 emissions by monthly temporal profile (includes federal waters but not non-US sources)

Monthly profile	CO	NH3	NOX	PM10	PM2.5	SO2	VOC
19531	57,519	100	592,149	8,021	7,157	15,777	26,083
GLCMV1	4	0	44	1	1	1	2
GLCMV10	21	0	173	4	3	6	6
GLCMV11	17	0	145	3	3	5	5
GLCMV12	4	0	37	0	0	1	1
GLCMV5	58	0	610	8	7	15	26
GLCMV8	6	0	51	2	1	2	3
GLCMV9	1	0	4	0	0	0	0

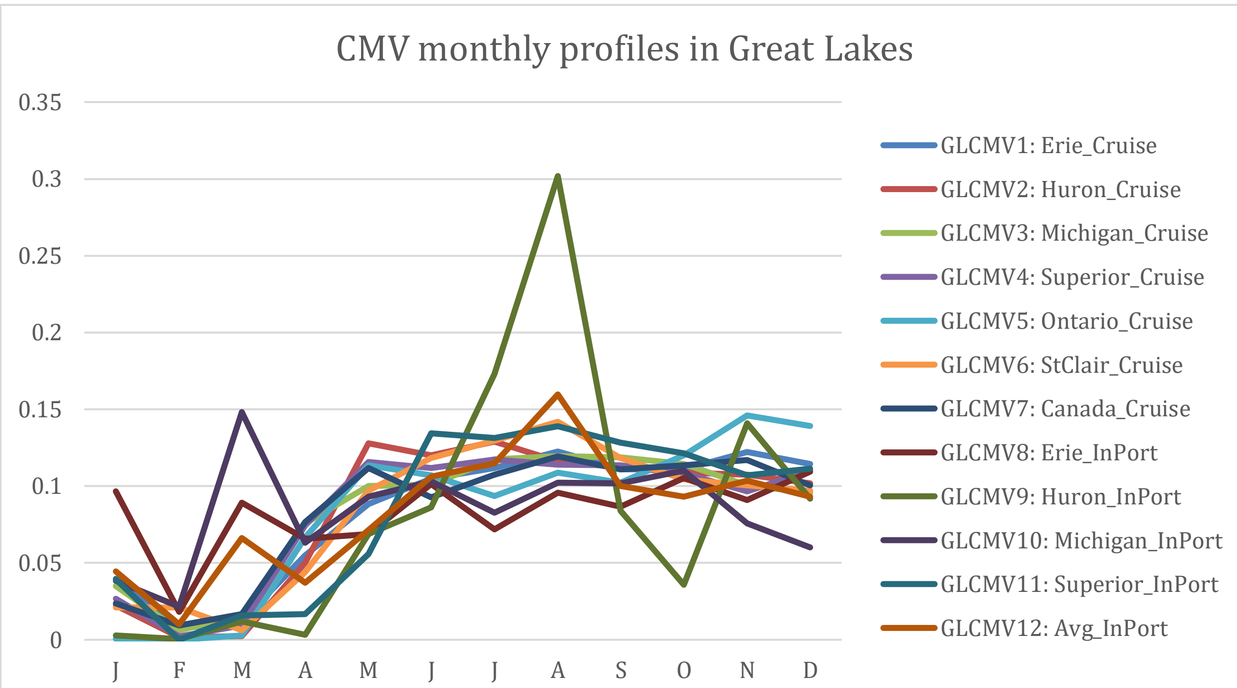

Figure 1. CMV Great Lakes 2014-based monthly temporal profiles

Chemical Speciation

The cmv_c3 sector includes emissions for particulate matter < 2.5 μm ($PM_{2.5}$), oxides of nitrogen (NOx), and VOC, among other criteria pollutants. These three inventory pollutants must be converted to air quality modeling species through an emissions processing step referred to as "chemical speciation". The U.S. EPA SPECIATE[5] database was used to develop

[5] https://www.epa.gov/air-emissions-modeling/speciate-version-45-through-40

factors to map the inventory species to the chemical species required for air quality modeling. All of the emissions in the cmv_c3 sector were assigned the $PM_{2.5}$ speciation profile 5675AE6 (Marine Vessel – Auxiliary Engine – Marine Gas Oil) and the VOC speciation profile 2480 (Industrial Cluster, Ship Channel, Downwind Sample). 5675AE6 is an update of profile 5675 to support AE6 PM speciation. The cmv_c3 NOx emissions were speciated using a 90:9.2:0.8 split for NO:NO2:HONO.

5. Emissions Projection Methods

Growth rates for cmv_c3 emissions from 2016 to 2023 and 2028 were developed using a forthcoming EPA report on projected bunker fuel demand. The report projects bunker fuel consumption by region out to the year 2030. Bunker fuel usage was used as a surrogate for marine vessel activity. To estimate future year emissions of CO, CO2, hydrocarbons, PM10, and PM2.5, the bunker fuel growth rate from 2016 to 2023, and 2028 were directly applied to the estimated 2016 emissions.

Growth factors for NOx emissions were handled separately to account for the phase in of Tier 3 vessel engines. To estimate these emissions, the NOx growth rates from the EPA C3 Regulatory Impact Assessment (RIA)[6] were refactored to use the new bunker fuel usage growth rates. The assumptions of changes in fleet composition and emissions rates from the C3 RIA were preserved and applied to the new bunker fuel demand growth rates for 2023, and 2028 to arrive at the final growth rates.

The 2023 and 2028 projection factors are shown in Table 4. Some regions for which 2016 projection factors were available did not have 2023 or 2028 projection factors specific to that region, so factors from another region were used as follows:

- Alaska was projected using North Pacific factors.
- Hawaii was projected using South Pacific factors.
- Puerto Rico and Virgin Islands were projected using Gulf Coast factors.
- Emissions outside Federal Waters (FIPS 98) were projected using Total factors.

[6] https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1005ZGH.TXT

Table 4. 2016-to-2023 and 2016-2028 CMV C3 projection factors

Region	2016-to-2023 NOX	2016-to-2023 other pollutants	2016-to-2028 NOX	2016-to-2028 other pollutants
US East Coast	-6.05%	27.71%	-7.54%	49.71%
US South Pacific	-24.79%	20.89%	-33.97%	45.86%
US North Pacific	-3.37%	22.57%	-4.07%	41.31%
US Gulf	-6.88%	20.82%	-12.40%	36.41%
US Great Lakes	8.71%	14.55%	19.80%	28.29%
Total	23.09%	23.09%	42.58%	42.58%

6. Emissions Processing Requirements

CMV_c3 emissions were processed for air quality modeling using the Sparse Matrix Operator Kernel Emissions (SMOKE[7]) modeling system. Because day-of-week temporalization is flat for all sources, a single representative day per month is processed. This cmv_c3 sector was processed through SMOKE as point sources. This is a 3-D sector in which all emissions are output to an inline point source file to support plume rise calculations within the air quality model. No 2-D gridded emissions were generated for this sector.

7. Emissions Summaries

Table 5 compares annual, national total cmv_c3 emissions for the 2016 beta platform to cmv_c3 emissions from previous modeling platforms. Table 6 and Table 7 show similar comparisons for state total cmv_c1c2 NOx and SO_2 emissions, respectively. Figure 2 and Figure 3 are gridded emissions plots of annual total NOx and SO_2. Figure 4 shows county density maps of cmv_c3 2016 and 2023 NOx emissions, and comparisons between 2016 and 2023 emissions. Additional cmv_c3 plots and maps are available online through the LADCO website[8] and the Intermountain West Data Warehouse[9].

Descriptions of the emissions platform cases shown in the tables and plots below are as follows:

2011en, 2023en, 2028el = Final 2011, 2023, and 2028 cases from the 2011v6.3 platform
2014fd = NEI2014v2 and 2014 NATA
2016fe = 2016 alpha platform (grown from NEI2014v2)

[7] http://www.smoke-model.org/index.cfm
[8] https://www.ladco.org/technical/modeling-results/2016-inventory-collaborative/
[9] http://views.cira.colostate.edu/iwdw/eibrowser2016

2016ff, 2023ff, and 2028ff = 2016, 2023, and 2028 cases from the 2016 beta platform

Table 5. Comparison of national total annual CAPS cmv_c3 emissions (tons/yr)

Pollutant	2011en	2014fd	2016fe	2016ff	2023en	2023ff	2028el	2028ff
CO	75,190	57,395	57,395	55,827	122,168	69,385	150,243	81,054
NH3	65	97	97	97	65	120	72	140
NOX	839,503	596,198	596,198	574,298	750,163	515,933	709,936	492,438
PM10	37,570	19,187	19,187	7,790	8,142	9,678	10,109	11,301
PM2.5	34,097	17,775	17,775	6,948	7,341	8,633	9,122	10,081
SO2	303,908	158,990	15,899	15,317	18,137	19,025	22,679	22,208
VOC	31,757	26,042	26,042	25,326	51,668	31,482	63,535	36,778

Table 6. Comparison of state total annual NOx cmv_c3 emissions (tons/yr)

State	2011en	2014fd	2016fe	2016ff	2023en	2023ff	2028el	2028ff
Alabama	969	1,099	1,099	1,088	723	1,013	601	953
Alaska							14,640	
California		27	27	24		18		16
Connecticut	1,585	599	599	594	1,408	558	1,329	549
Delaware	2,216	2,329	2,329	2,309	1,969	2,169	1,857	2,135
D.C.	2	0	0	0	1	0	1	0
Florida	24,764	33,003	33,003	32,703	21,500	30,591	19,218	29,461
Georgia	2,088	3,612	3,612	3,581	1,855	3,364	1,674	3,311
Hawaii							3,021	
Illinois	112	87	87	83	106	90	106	100
Indiana	15	18	18	17	14	18	14	20
Louisiana	20,217	13,695	13,695	13,564	15,082	12,630	12,546	11,881
Maine	1,215	477	477	473	1,079	444	1,018	437
Maryland	10,077	3,230	3,230	3,202	8,952	3,008	8,444	2,960
Massachusetts	3,997	1,484	1,484	1,471	3,550	1,382	3,349	1,360
Michigan	4,696	37	37	35	4,453	38	4,463	42
Minnesota	255	150	150	142	242	155	242	170
Mississippi	1,065	1,035	1,035	1,025	794	955	661	898
New Hampshire	478	268	268	265	425	249	401	245
New Jersey	5,963	4,430	4,430	4,392	5,297	4,126	4,997	4,061
New York	5,594	2,139	2,139	2,093	5,112	2,060	4,931	2,110
North Carolina	1,578	8,234	8,234	8,164	1,402	7,669	1,322	7,548
Ohio	760	52	52	49	721	53	723	59
Oregon		799	799	707		532		467
Pennsylvania	3,657	1,192	1,192	1,180	3,322	1,114	3,189	1,102
Rhode Island	237	429	429	425	211	399	199	393
South Carolina	2,211	7,109	7,109	7,048	1,965	6,621	1,773	6,516
Texas	15,600	7,357	7,357	7,287	11,638	6,785	9,681	6,383

State	2011en	2014fd	2016fe	2016ff	2023en	2023ff	2028el	2028ff
Virginia	3,291	4,132	4,132	4,097	2,923	3,849	2,758	3,787
Washington	12,184	11,170	11,170	10,145	10,303	9,803	9,310	9,732
Wisconsin	548	77	77	74	519	80	521	88
Offshore to EEZ	714,130	487,929	487,929	468,064	644,596	416,157	596,945	395,655

Table 7. Comparison of state total annual SO2 cmv_c3 emissions (tons/yr)

State	2011en	2014fd	2016fe	2016ff	2023en	2023ff	2028el	2028ff
Alabama	678	310	31	31	34	37	40	42
Alaska							633	
California		7	1	1		1		1
Connecticut	994	152	15	15	61	19	66	23
Delaware	1,727	1,700	170	168	106	215	114	252
D.C.	1	0	0	0	0	0	0	0
Florida	18,323	8,596	860	852	1,097	1,061	1,349	1,223
Georgia	1,621	1,006	101	100	99	127	123	149
Hawaii							178	
Illinois	71	28	3	3	3	3	3	3
Indiana	8	6	1	1	0	1	0	1
Louisiana	13,962	3,626	363	360	708	435	815	492
Maine	843	132	13	13	52	17	56	20
Maryland	5,898	873	87	86	361	110	389	129
Massachusetts	3,147	392	39	39	192	50	208	58
Michigan	2,364	12	1	1	102	1	111	1
Minnesota	129	48	5	5	6	5	6	6
Mississippi	791	276	28	27	40	33	46	37
New Hampshire	378	205	21	20	23	26	25	30
New Jersey	3,491	1,578	158	156	213	199	230	234
New York	3,287	558	56	55	176	68	187	79
North Carolina	1,737	2,053	205	203	106	259	115	304
Ohio	384	17	2	2	17	2	18	2
Oregon		240	24	21		26		31
Pennsylvania	3,166	367	37	36	181	46	193	54
Rhode Island	496	111	11	11	30	14	33	17
South Carolina	2,023	1,806	181	179	124	228	154	267
Texas	4,708	2,334	233	232	239	280	275	316
Virginia	2,410	1,127	113	112	147	142	159	167
Washington	12,078	11,241	1,124	1,026	695	1,258	815	1,450
Wisconsin	275	25	3	2	12	3	13	3
Offshore to EEZ	218,916	120,164	12,016	11,560	13,313	14,358	16,324	16,817

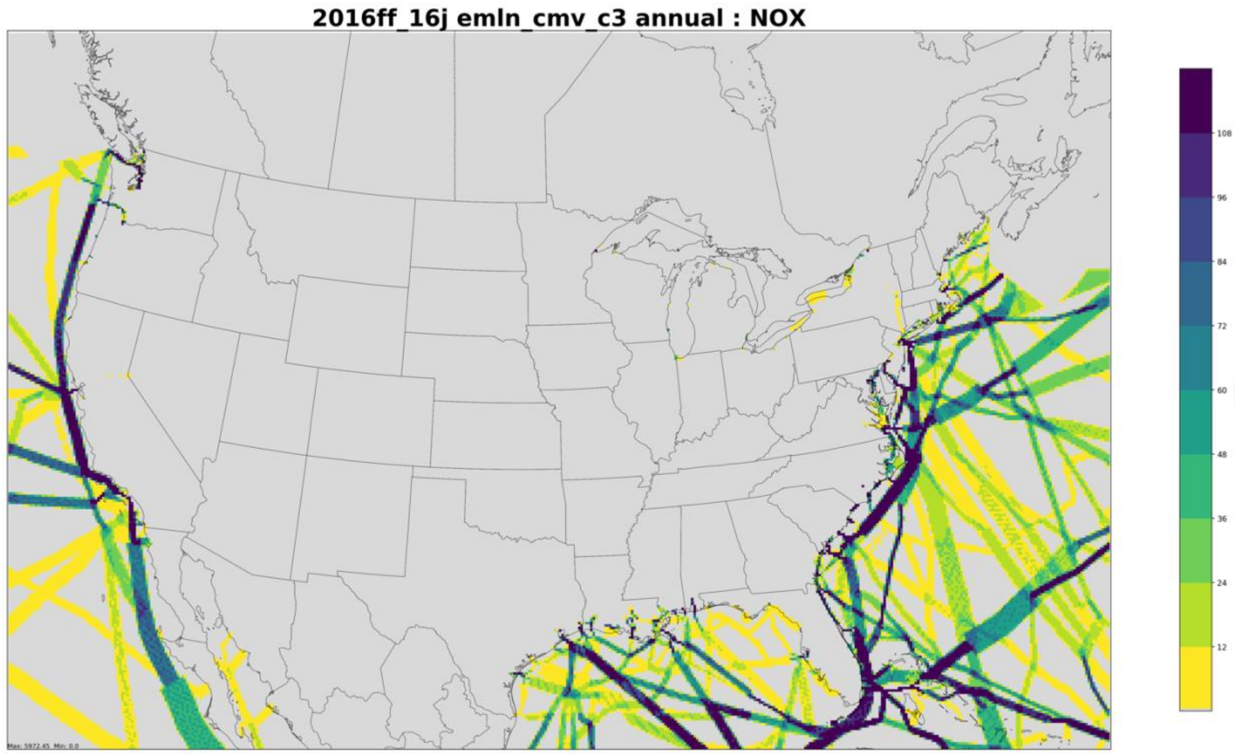

Figure 2. Gridded 2016 NOx emissions from cmv_c3

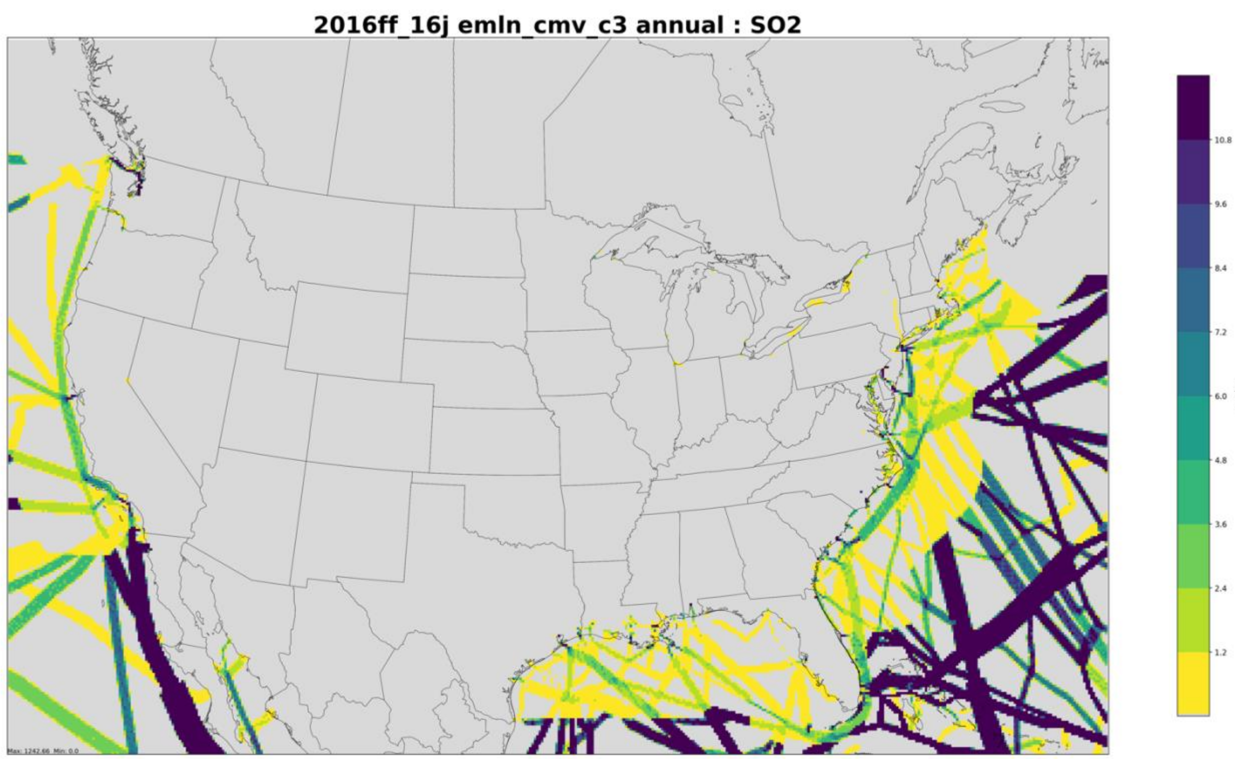

Figure 3. Gridded 2016 SO_2 emissions from cmv_c3

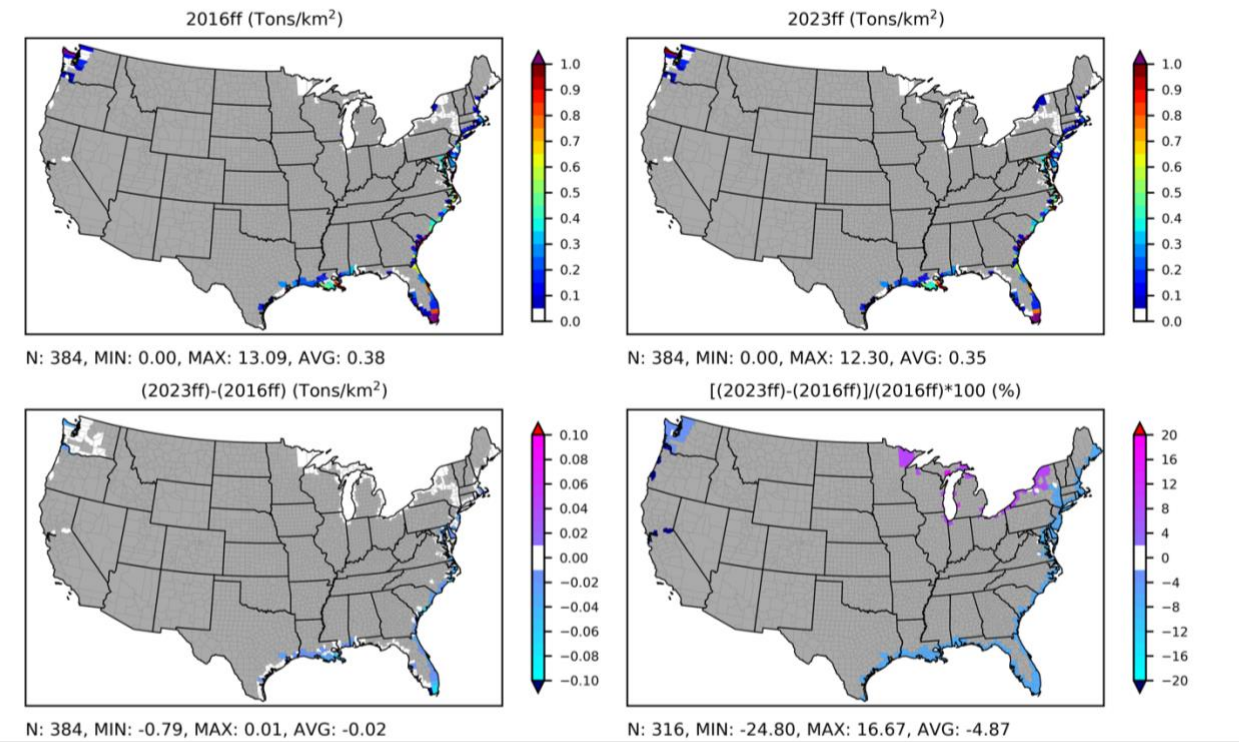

Figure 4. 2016 and 2023 NOx Density from cmv_c3; note only in-shore emissions are shown in these plots