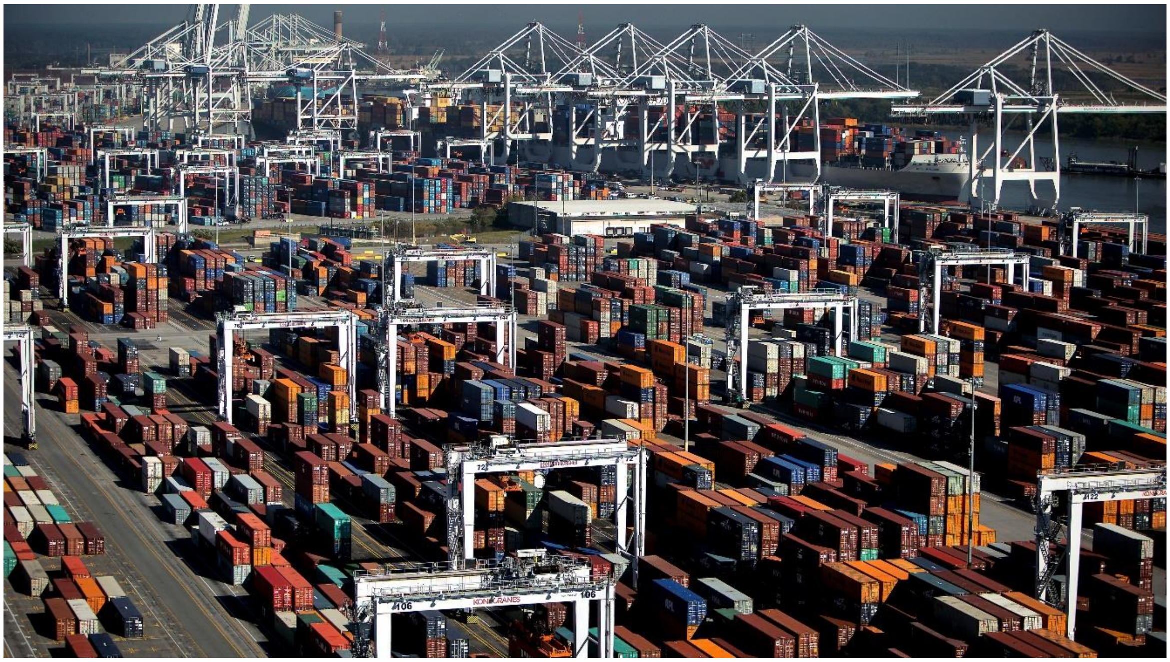
Detailed Criteria and Hazardous Air Pollutant Emission Inventories for the Ports of Savannah and the Savannah Metro Area

Executive Summary



Garden City Terminal at Dawn. Container ships working at the Georgia Ports Authority Garden City Terminal, Monday, Oct. 27, 2014, in Savannah, GA (GPA Photo/Stephen B. Morton).

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PURPOSE:

In this project, a detailed spatial, temporal, and chemically speciated emission inventory was developed for the Georgia Ports Authority's (GPA) Garden City Terminal (GCT). Emissions were calculated for the GCT using a detailed estimation approach in which data from actual equipment and vessels used, container moves, time-of-use, time-in-mode, and fuel, equipment, or process modifications were tracked from port logs and records for the specific periods of interest. This represents the highest level of port emission estimations possible, short of direct measurement. Additionally, contemporaneous inventories were also developed for the Savannah metro area so that the GCT emissions could be more readily and directly compared to other point, on-road mobile, area, and non-road mobile sources of emissions in the Savannah metro area. GCT and Savannah area emissions were then used in advanced "state-of-the-art" computer models to simulate air quality for the Savannah metropolitan area.

The GPA was particularly interested in understanding the effect on emissions and air quality resulting from changes in operations and equipment at the GCT that occurred between the years 2002 (pre-treatment) and 2010 (post-treatment). These changes included an approximate doubling of the rate of containers moved from the beginning of the period to the end of the period; a change in fuel used by some cargo handling equipment; and the replacement of some diesel-powered equipment with electric-powered equipment.

SCOPE AND SCALE:

In selecting the study periods, careful consideration was given to time frames when air quality in the Savannah metro area has been "least good." That is, the Savannah area has always met all National Ambient Air Quality Standards (NAAQS) prescribed by the US EPA under the federal Clean Air Act. Air quality in the region does vary, however, within the acceptable ranges of the NAAQS and sometimes approaches the limit of these acceptable ranges. A dataset consisting of all historically available air quality observations was assembled and assessed for when air pollutant concentrations tend to be highest in the Savannah metro region. Looking specifically at air pollutant observations in the pre-treatment year of 2002, the period July 13-22 included several days when ozone and PM2.5 pollutant concentrations were elevated relative to the remainder of the year. The period included 4 of the 10 highest daily observed concentrations in 2002 of ozone, and 2 of the 10 highest daily observed concentrations in 2002 of PM2.5. In the "post-treatment" year of 2010, July 6-15 was selected as a seasonally comparable period with 2 of the 10 highest daily observed ozone concentrations and 1 of the 10 highest daily observed PM2.5 concentrations occurring during the year. Spatially, the study intensively focused on the GCT and operations therein. This includes all emissions related to managing incoming and outgoing vessels as they were received into and discharged from the shipping channel (i.e. from open sea to berth in the GCT). Emissions were estimated for each vessel, pilot or tug boat, cargo handling equipment, truck, or railroad engine that was employed by the GCT during the respective periods of study in 2002 and 2010. Emissions were allocated during the time of day (by hour) and location (within a 1km by 1km grid) in which they were released (Figure 1). All other emissions in the Savannah metro area that were not related to the GCT were estimated from the US EPA's National Emission Inventory (NEI). Emissions from the NEI were allocated to the same temporal (i.e. hourly) and spatial (i.e. 1km X 1km) frames. The Savannah metro area was presumed to consist of 5 counties in Georgia (Chatham, Effingham, Bryan, Liberty, and Long) and one county in South Carolina (Jasper). Emissions outside of the Savannah metro area were also estimated from the NEI and allocated accordingly in time and space (but at coarser spatial resolutions of 4km, 12km, and 36km and accounting for emissions across the whole continental US (Figure 2).

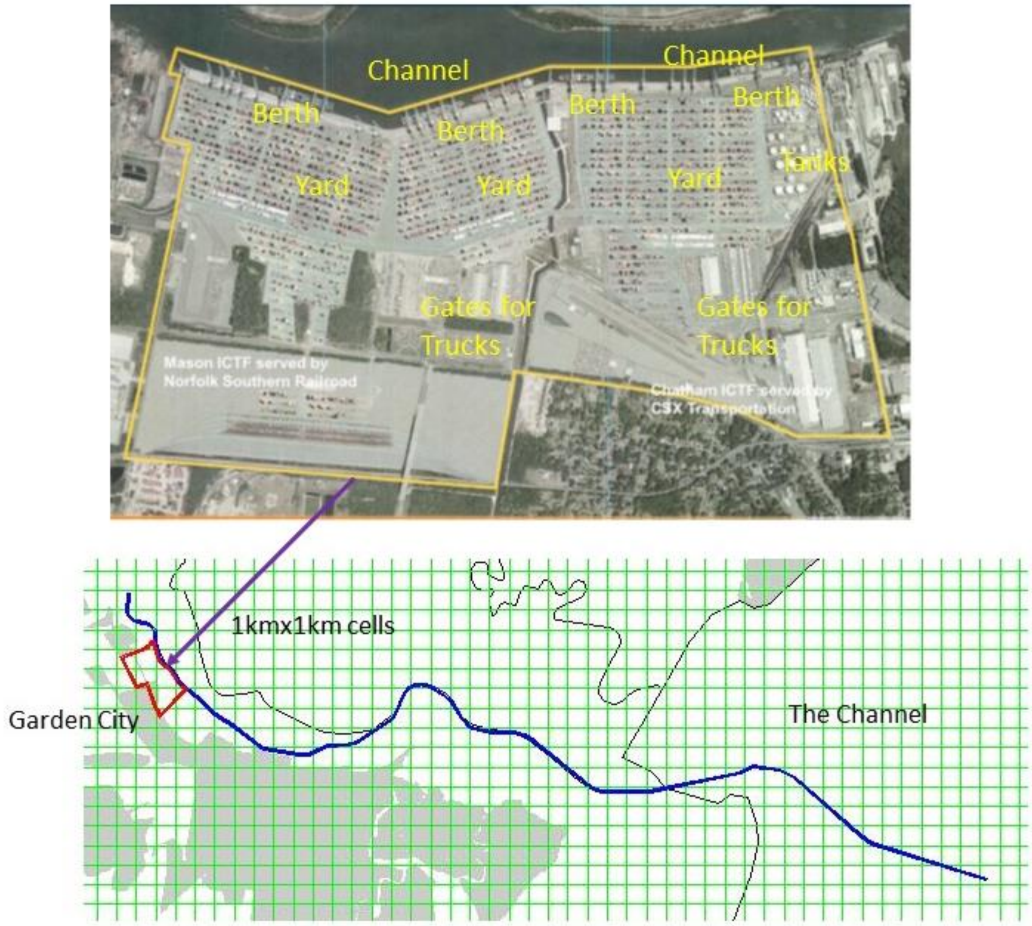


Figure 1. Garden City Terminal in relation to the City of Savannah and the Savannah River Ship Channel.

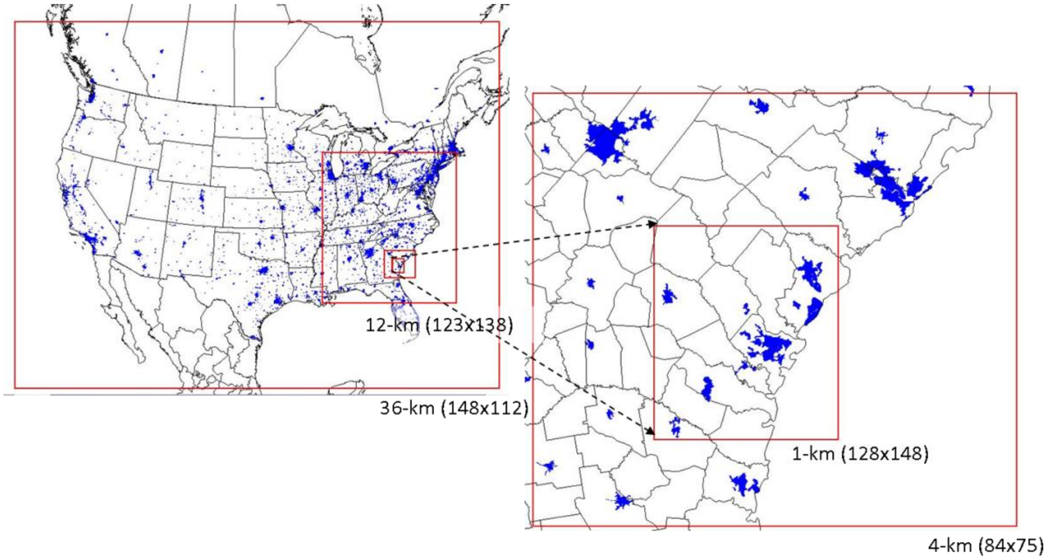


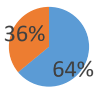
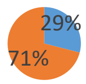
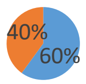
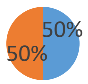
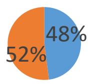
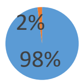
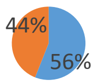
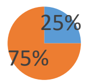
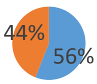
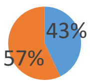
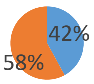
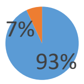
Figure 2. Full nested 36km, 12km, 4km, and 1km resolution air quality modeling domans.

EMISSIONS:

For the two study periods, the GPA provided paper records detailing all operations of the GCT. These included vessel calls to the port; deployment of pilot and tug boats for guiding the vessels through the ship channel to the berth at the GCT; the use of various cargo handling equipment (cranes, forklifts, jockey trucks, etc.) for the loading, unloading, and distribution of containers to and from the vessels and their movement within the GCT; and the transfer of containers from the GCT to points outside of the GCT by truck and rail transport. The records generally consisted of the type and age of vessel/vehicle/equipment used, time and duration of use, and type and/or amount of fuel used. Emission factors for each vessel/vehicle/equipment used were compiled from US EPA databases, independent GPA studies, original equipment manufacturers' specifications, or previously published rates found in the scientific literature. From this data, emissions were estimated for all sources related to the GCT operations for ozone pollution precursors (nitrogen oxides [NOx] and Volatile Organic Compounds [VOCs]), carbon monoxide (CO), particulate matter (both coarse [PM10], and fine [PM2.5]), and precursors that contribute to the secondary production of particles in the atmosphere (sulfur dioxide [SO2] and ammonia [NH3]). Emissions were then allocated to the 1-km by 1-km spatial grid overlaid on the geographic area at the location where the emissions were released to the atmosphere. They were also distributed across the period in 1-hour increments at the time at which they were estimated to have been released based on shift schedules, equipment records, and other time logs.

Table 1 shows the daily average GCT related emissions during the 2002 and 2010 study periods, and the relative share of these emissions attributed to vessels visiting the terminal (i.e. ship-based) vs. the terminal's operations (i.e. shore-based). Between 2002 and 2010, daily average emissions for ozone precursors (NOx and VOCs), carbon monoxide (CO), and ammonia (NH3) increased, while emissions of particulate matter (PM10 and PM2.5) and sulfur dioxide (SO2) decreased. The relative share between ship and shore emissions for each of the pollutants remained generally consistent between the two periods: vessels were the majority source of NOx, VOC, and SO2 emissions; the terminal was the dominant source of CO and NH3 emissions; and there was generally a balance between the vessels and terminal shares as sources of PM10 and PM2.5 emissions.

Table 1. Daily average emissions from Vessels and Garden City Terminal operations, July 13-22, 2002 vs. July 6-15, 2010.

	Year	NOx	CO	VOC	PM10	PM2.5	SO2	NH3
Total (metric tons / day)	2002	5.2346	1.2147	0.3034	0.2296	0.2166	0.9264	0.0012
	2010	7.1245	2.0647	0.4883	0.2068	0.1958	0.1347	0.0026
	% Change	↑ 36%	↑ 70%	↑ 61%	↓ -10%	↓ -10%	↓ -85%	↑ 117%
2002 Relative Share	Vessels							
	Terminal							
2010 Relative Share	Vessels							
	Terminal							

Changes between 2002 and 2010 in emissions from any GCT related source are due to: 1) changes in the amount of port activity (i.e. # of containers processed through the GCT); or 2) changes in port operations (e.g. different equipment, fuels, or operating procedures). To understand and isolate the impact of the former, the emissions were "normalized" and re-calculated to show "emissions per TEU" (TEU = "Twenty-foot Equivalent Unit," a measure of port container throughput). In 2002, the daily average TEU picks at the GCT were 1935 during the study period. In 2010, the daily average TEU picks at the GCT were 4767 during the study period, an increase of 2.46X over 2002. Table 2 shows emissions per TEU.

Table 2. Average emissions per TEU pick from all GCT activities (Vessels and Terminal), July 13-22, 2002 vs. July 6-15, 2010.

	Year	NOx	CO	VOC	PM10	PM2.5	SO2	NH3
Total (kg/TEU)	2002	2.7052	0.6277	0.1568	0.1186	0.1119	0.4787	0.0006
	2010	1.4946	0.4331	0.1024	0.0434	0.0411	0.0283	0.0005
	% Change	↓ -45%	↓ -31%	↓ -35%	↓ -63%	↓ -63%	↓ -94%	↓ -17%

Table 2 indicates that the GCT has made significant progress in lowering the rate of all pollutant emissions, but Table 1 suggests that for some pollutants (NOx, CO, VOC, and NH3), the decrease in the rate of emissions can be offset by the increase in the number of containers processed through the GCT and result in an overall increase in daily emissions. That is:

Total Emissions = (Emissions per TEU) X (Number of TEUs)

Between 2002 and 2010, the "Emissions per TEU" decreased, but the "Number of TEUs" increased.

Table 3 further decomposes the total emissions per TEU shown in Table 2 into sub-categories. Here it is evident that the changes in emission rates between 2002 and 2010 were not uniform across all operational sectors of the GCT. Perhaps the greatest contrast is the increase in the rate of emissions related to trucks (here trucks are defined as the trucks that pick-up or drop-off containers at the GCT and that enter and exit through the GCT gates; they do not refer to the trucks that serve the GCT within the terminal [e.g. jockey trucks]). This increase in emissions rates for trucks runs counter to the trend of every other emissions source experiencing a reduction in emissions rates per TEU.

Table 3. Average emissions per TEU pick from all GCT activities by source, July 13-22, 2002 vs. July 6-15, 2010.

kg/TEU	Year	NOx	CO	VOC	PM10	PM2.5	SO2	NH3
Vessels	2002	1.7213	0.1809	0.0947	0.059	0.0541	0.4429	0.0000
	2010	0.8391	0.1098	0.0575	0.0188	0.0172	0.0276	0.0000
	% change	↓ -51%	↓ -39%	↓ -39%	↓ -68%	↓ -68%	↓ -94%	0%
Tugs	2002	0.4459	0.2275	0.0238	0.0282	0.0273	0.0003	0.0002
	2010	0.1826	0.1164	0.0122	0.0072	0.007	0.0000	0.0001
	% change	↓ -59%	↓ -49%	↓ -49%	↓ -74%	↓ -74%	↓ -100%	↓ -50%
Cargo Handling Equipment	2002	0.4343	0.1723	0.0293	0.0282	0.0273	0.0335	0.0003
	2010	0.3282	0.1608	0.0229	0.0136	0.0132	0.0004	0.0003
	% change	↓ -24%	↓ -7%	↓ -22%	↓ -52%	↓ -52%	↓ -99%	0%
Trucks	2002	0.0908	0.0224	0.0053	0.002	0.002	0.0014	0.0001
	2010	0.1369	0.0337	0.008	0.0031	0.003	0.0002	0.0002
	% change	↑ 51%	↑ 50%	↑ 51%	↑ 55%	↑ 50%	↓ -86%	↑ 100%
Locomotives	2002	0.0115	0.008	0.0019	0.0012	0.0012	0.0006	0.0000
	2010	0.0073	0.0056	0.0011	0.0007	0.0007	0.0000	0.0000
	% change	↓ -37%	↓ -30%	↓ -42%	↓ -42%	↓ -42%	↓ -100%	0%

The US EPA did implement new emissions standards for on-road, heavy-duty diesel engines (i.e. truck) beginning with model-year vehicles manufactured in 2007, but due to the time it takes for the commercial fleet to turnover, these new standards made little difference in the emissions rates of trucks entering the GCT between the study years of 2002 and 2010. That is, even by 2010, most trucks calling on the GCT were manufactured before the new engine standards were required. One rule that did have a significant impact on the emissions from trucks, however, was the 2006 rule that reduced the sulfur content of on-road diesel fuel from 500 ppm to 15 ppm. Low-sulfur diesel fuel was a prerequisite for the coming 2007 diesel engine rule that introduced the use of catalytic-convertor type technologies in diesel engines and for which sulfur, if still present in high concentrations in diesel fuel, reduces the effectiveness of the catalysts. For the GCT then, even though the commercial fleet calling on the terminal in 2010 mostly was not yet equipped with modern emissions control technologies that could take full advantage of the low-sulfur diesel fuel to reduce most of the emissions of concern, the low-sulfur diesel fuel requirement did have a direct beneficial impact on lowering sulfur emissions from trucks. In subsequent years, the rate of emissions for the other pollutants should decrease also as the fleet of trucks continues to turnover and older model trucks without catalyst-based emission control technologies are replaced with newer trucks with these technologies.

Since the rate of emissions by trucks (other than sulfur) did not change significantly between 2002 and 2010, the approximate 50% increase in emissions per TEU by trucks must be explained by another factor. Though there are no statements, rules, or policies that point to an intentional change, it does appear that a modal shift towards truck transport of containers (relative to rail, i.e. locomotive) occurred between 2002 and 2010. As noted previously, daily average container throughput (as measured by TEUs) at the GCT increased by 2.46X between the 2002 10-day study period and the 2010 10-day study period. The average number of trucks passing daily through the GCT gates (in and out) during these times, however, increased from 1612 in 2002 to 5984 in 2010, for an increase of 3.71X. See Figure 3.The ratio of the increase in truck gate counts to the increase in TEU picks (i.e. 3.71 / 2.46) suggests that the rate of truck activity increased 1.51X greater than the rate of TEU increase – and appears to explain the ~50% increase in non-sulfur emissions per TEU by trucks.

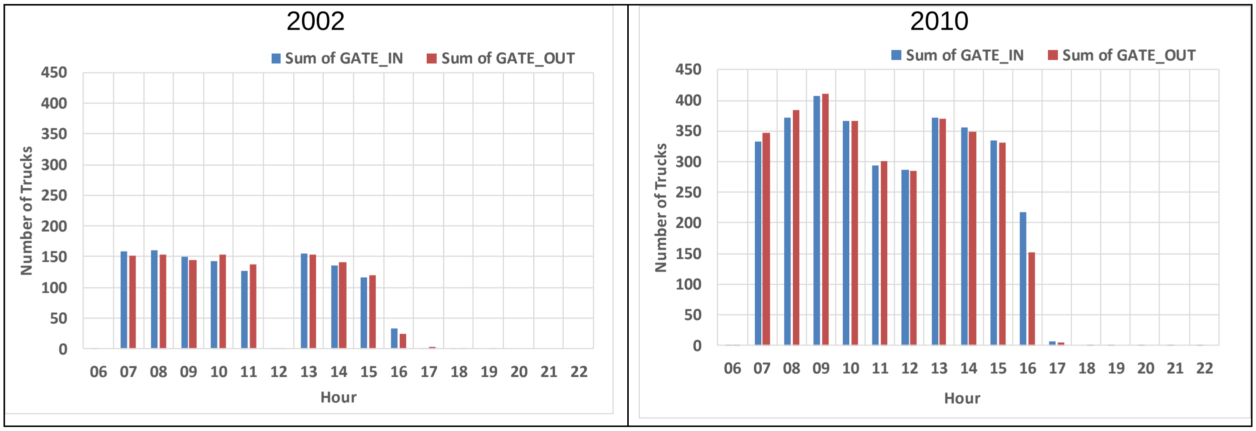


Figure 3. Average daily truck counts by time of day through the GCT gates for the July 13-22, 2002 and July 6-15, 2010 study periods.

The primary reasons for the decrease in the rate of emissions per TEU for the other sources at the GCT were:

- Vessels – Decreases in emissions of SO2 were most immediately a direct result of federal and international regulations that limited the permissible content of sulfur in diesel and other (e.g. bunker) marine fuels. These rules were largely implemented in the intervening years between 2002 and 2010, and resulted also in some benefit to NOx, VOC, and CO emissions as newer mandated marine engines – taking advantage of the low sulfur fuels that permit the catalysts in emissions control technologies to function more effectively – were gradually introduced into the fleet. Finally, vessel emissions per TEU were also lower in 2010 relative to 2002 due to larger vessels delivering more containers per vessel call.
- Tugs – The reasons for the decrease in tug emissions follow the same reasons as the reduction in vessel emissions: low sulfur fuel, fleet turnover with new or remanufactured engines with emissions control technologies, and tugs operating on larger vessels handling higher numbers of containers per move.
- Cargo Handling Equipment – Decreases in the emissions of cargo handling equipment reflect the trend towards electrification and away from diesel and gasoline. This was especially apparent in

the emissions from ship-to-shore cranes in the period between 2002 and 2010. Low sulfur fuel and equipment turnover with newer engines also reduced emissions. Additionally, during the 2002-2010 interlude, the GPA introduced a diesel fuel additive that lowered emissions and was particularly effective for the jockey trucks that shuttle containers between the berths and the stacks.

- Locomotives – Lower sulfur fuel and locomotive fleet turnover may have had some impact on the reduction of emissions from locomotives, but the primary reason for the decrease in emissions from locomotives is due to the increase in TEUs handled by trucks instead of by locomotives. That is, as the number of TEUs processed by the GCT increased, locomotive activity changed at a less than proportional rate.

While this study was a comprehensive investigation of emissions only for 10 days in 2002 and 10 days in 2010, the normalization of emissions by TEU (Table 2 and Table 3) makes it possible to approximate the emissions for a full calendar year if the total number of TEU picks are known, and to compare the annualized emissions to other ports. This assumption ignores known seasonal variations such as increased evaporative emissions of VOCs in the summer, or decreased fuel efficiencies due to the use of air conditioning also in the summer, all of which are not insignificant, but neither are they large.

Annual GCT Emissions = (Emissions per TEU) X (Annual TEU Throughput)

Table 4 shows the estimated annualized emissions from the GCT in 2002 and 2010, and published emissions from the Ports of Los Angeles in 2009 and Houston in 2007. Emissions estimates from these latter two ports include non-container ships calling on the ports so that a direct comparison of emissions rates by TEU are not immediately possible. Nonetheless, overall total emissions from the GCT are considerably less than at the Ports of Los Angeles and Houston.

Table 4. Estimated annualized emissions (metric tons/year) at the GCT in 2002 and 2010 and comparison to published emissions from the Port of Los Angeles (2009) and the Port of Houston (2007).

Port	NOx	CO	VOC	PM10	PM2.5	SO2	TEU	CALLs
GCT 2002	3593	834	208	158	149	636	1,327,926	983*
GCT 2010	3943	1143	270	114	108	75	2,637,643	1907*
Port of LA 2009	10,222	2,525	545	465	396	2,211	6,748,995	2010 (1355*)
Port of Houston 2007	6,105	1,265	315	409	351	3,036	1,768,627	6957 (814*)

* Container ship calls

As will be discussed extensively in the next section on Air Quality, emissions released into the atmosphere from the GCT can have an impact on air quality by themselves, and by also contributing to and reacting with the larger load of gases and aerosols emitted by other natural and anthropogenic (i.e. related to human and societal activities) sources. To get a sense of the quantity of the GCT emissions relative to other emissions sources in the Savannah airshed, Table 5 and Table 6 shows the emissions of the GCT relative to other sources in the Savannah metro area.

Within the emissions source categories shown in Table 5 and Table 6, emissions from the GCT (except trucks) would be normally classified as non-road mobile sources. Likewise, the trucks entering and leaving the GCT would be classified as on-road mobile sources. Unlike the other non-road and on-road mobile sources, however, the emissions from the GCT are relatively concentrated within a small region. The other non-road and on-road mobile sources, along with the area, and biogenic sources are more often distributed broadly across the spatial domain. In geographically confining the GCT sources to the terminal grounds (and the ship channel for vessels in transit to and from the terminal), emissions from the GCT are similar to a point source (e.g. emissions released through a stationary smokestack) except that the GCT emissions are emitted at the surface and at relatively cool temperatures that limit their loft in the atmosphere. Thus, although the GCT operations constitute a relatively small fraction of the total emissions within the Savannah airshed, the concentration of emissions in one small area and their proximity to populated areas warrant further investigations into their impact on air quality.

*Table 5. Episodic daily average emissions (metric tons / day) at the GCT in **2002**, and comparison to the categorized emissions within the 1km X 1km modeling domain consisting of the counties of Chatham, Effingham, Bryan, Liberty, and Long, GA; Jasper County, SC; and parts of 8 surrounding counties (i.e. the Savannah Metro Area).*

2002 episodic average (July 13-22,2002)							
	NOx	**VOC**	**PM25**	**PM10**	**SO2**	**NH3**	**CO**
GCT	5.2346	0.3034	0.2166	0.2296	0.9264	0.0012	1.2147
Point	55.4019	14.5166	5.1050	6.7142	114.6118	0.4201	36.2272
On-road (non GCT)	60.5245	60.8059	1.1982	1.6331	2.5375	2.2390	560.6855
Non-road (non GCT)	28.7305	37.4005	2.9219	3.1104	3.2300	0.0134	255.8649
Area	4.9456	58.5769	9.1431	43.6961	7.2976	4.1455	10.5741
Biogenic	7.9567	1280.9340	0	0	0	0	111.6316
Total	162.7938	1452.5373	18.5848	55.3834	128.6033	6.8192	976.198
GCT % of Total	3.22%	0.02%	1.17%	0.41%	0.72%	0.02%	0.12%

*Table 6. Episodic daily average emissions (metric tons / day) at the GCT in **2010**, and comparison to the categorized emissions within the 1km X 1km modeling domain consisting of the counties of Chatham, Effingham, Bryan, Liberty, and Long, GA; Jasper County, SC; and parts of 8 surrounding counties (i.e. the Savannah Metro Area).*

2010 episodic average (July 06-15,2010)							
	NOx	**VOC**	**PM25**	**PM10**	**SO2**	**NH3**	**CO**
GCT	7.1245	0.4883	0.1958	0.2068	0.1347	0.0026	2.0647
Point	25.5576	15.5985	5.9873	6.8160	28.3750	2.0914	20.1947
On-road (non GCT)	17.8125	13.5655	0.1307	0.1371	0.0073	0	57.0539
Non-road (non GCT)	22.1051	37.2329	1.9040	2.0154	0.1008	0.0277	200.0148
Area	2.6005	38.0950	13.4594	76.1346	1.3830	4.9467	32.6930
Biogenic	4.9806	1323.5830	0	0	0	0	106.3614
Total	80.1808	1428.5632	21.6772	85.3099	30.0008	7.0684	418.3825
GCT % of Total	8.89%	0.03%	0.90%	0.24%	0.45%	0.04%	0.49%

AIR QUALITY:

As noted before, increased container throughput (as measured by TEUs) can partially or wholly offset reductions in the rate of air pollutant emissions due to improvements in efficiencies, modernization of equipment, changes in fuels used, the implementation of emissions control technologies, and other changes in GCT equipment and operations. Continued growth in TEU throughput will challenge the Georgia Port Authority to search for additional opportunities to reduce the rate of emissions associated with the GCT's operations if the goal is to reduce, or even just to maintain, emissions at a fixed amount. Emissions targets, however, are not typically goals to be pursued unto themselves, especially for a region that is currently meeting all state and federal air quality standards. Outside of regulatory requirements, emissions are a concern only as they relate to air quality (and in turn, air quality is a concern only as it relates to human and ecological health). The primary objective of this study was to understand the contribution that the GCT makes to the quality of the air of the Savannah metropolitan area (and by proxy, the health of the residents residing in the region). To meet this objective, the emissions calculated for the GCT were used to drive two different air quality simulation computer models. Unlike observational studies, models allow investigators to identify and isolate the impact of single sources, like the GCT, from impacts contributed by other sources.

The first model used was the Community Multi-scale Air Quality (CMAQ) model. CMAQ is the state-of-the-art model developed and used by regulatory agencies (e.g. US EPA and GA EPD) and science laboratories (e.g. Georgia Tech and NASA) to simulate the transport and chemical transformation of pollutants in the atmosphere. It is often used as a research and planning tool to understand the effects of emissions and weather on air quality. In Georgia, it has been used extensively by the Georgia Environmental Protection Division to develop State Implementation Plans for attaining and maintaining ozone and PM2.5 air quality standards in Atlanta. It has also been used by researchers at Georgia Tech to forecast next day air quality in Atlanta, Macon, and Columbus; to assess the air quality impacts from prescribed burning activities in middle and south Georgia; to assess the relative impact of local and distant sources of emissions on air quality along Georgia's Fall Line; to study haze in the North Georgia Mountains; and to study the impact of air quality on the epidemiological health of residents in the Southeastern US. It is only because of this extensive previous and ongoing employment of CMAQ in Georgia that its use in this study of the GCT is even possible. The cost of a CMAQ modeling study of a single air quality episode – if started from scratch – can typically run $1M or more. This GCT study leverages existing modeling setups and databases, and makes extensive use of a knowledge base about regional emissions, climate, and weather to complete the study at considerably lower cost. There are caveats, however, because of the study constraints. One primary concern is the proximity of Savannah to the Atlantic coast and the challenges it presents. Coastal areas, like Savannah, can be more difficult to accurately model than inland areas, like Atlanta, because of highly variable and localized land-sea breeze effects. The exact timing and location of these effects requires a level of precision and attention that was not possible under the constraints of the study. A secondary concern was the scarcity of observed data from 2002 and 2010 with which to compare the model results and to assess model performance. As an area in attainment of all applicable federal and state air quality standards, there were few air quality monitoring stations collecting data in the region in 2002 and 2010. Because of these two principle shortcomings, the model results are presented "as is." In an absolute sense, they should not be viewed as accurate simulations of air quality in Savannah (they may in fact be, but there is not enough observational data to assess the performance of the model). The investigators can assert, though, that the model results can be used to understand the contribution of the GCT to air quality in the region relative to the contribution from all other sources in the Savannah metro area.

The second model used to simulate the impact of the GCT's operations on the surrounding area's air quality is called CALPUFF. CALPUFF is an air quality modeling system adopted by the US EPA as the preferred model for assessing long range transport of pollutants and for certain near-field applications involving complex meteorological conditions (such as the case of the GCT and its coastal surroundings). Different from the CMAQ, CALPUFF does not simulate the chemical transformation of pollutants. It does, however, simulate the transport of pollutants from the point of their release and follows them as they disperse more broadly into the atmosphere. This contrasts with CMAQ in which pollutants at the time they are released into the atmosphere "instantly" disperses those pollutants uniformly throughout the grid (and in the CMAQ application to the GCT, this was a grid of 1km X 1km in horizontal dimension and 20m in the vertical dimension). The implication of CMAQ's instantaneous mixing of emissions is that the pollutants are artificially diluted, and thus, the model may underestimate pollutant impacts in nearby areas. CALPUFF then, is used here to study these nearby impacts in which transport is important (but chemical transformation is not). CMAQ is used to study the regional impacts in which both transport and chemical transformation is important. As with the CMAQ model, though, the same caveats apply to CALPUFF in which the veracity of the absolute location, timing, and concentrations of pollutants has not been determined. That is, CALPUFF is informative of potential nearby impacts, but it cannot be considered conclusive without further study.

Figure 4 shows results from the CMAQ model for ozone air quality on 17 July 2002 and 12 July 2010. These were the days from the 2002 and 2010 modeled episodes in which the GCT impacts on the surrounding area's air quality were greatest. The figure focuses on Chatham County, with the panels on the left side of the figure showing the daily peak 8-hour average CMAQ predicted ozone concentration on 17 July 2002 (upper left) and 12 July 2010 (lower left). The panels on the right of the figure show the corresponding percent impact and the spatial extent of the impact of the GCT on the area's air quality. For ozone, the CMAQ simulations suggest that operations at the GCT lower ozone pollutant concentrations in the immediate vicinity of the terminal, and have negligible impact further away. While this result may seem antithetical to some, it is a commonly observed phenomenon of atmospheric chemistry. On the one hand, ozone (O_3) is formed in the atmosphere from a series of photochemical reactions involving nitrogen oxides (NOx), volatile organic compounds (VOCs) and sunlight:

$$\text{NOx} + \text{VOCs} + \text{sunlight} \rightarrow \text{O}_3$$

Further, the rates of chemical reactions that produce ozone are enhanced by the heat of the summer. Thus, given that the GCT operations simulated here include the emissions of NOx and VOCs in the summer month of July, it is reasonable to expect that this confluence should lead to the increase of ozone, not a decrease as the simulation shows. There is, however, another competing chemical reaction that also occurs. In high concentrations, NOx (in the form of NO) can also react with ozone reducing its concentration:

$$\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 + \text{O}_2$$

It is this second reaction that is dominating the impact of the GCT on ozone air quality in the Savannah area. As concentrations of NOx from the GCT move further downwind from the terminal, and their concentration in the atmosphere lessens through dispersion, the first reaction could become dominate again leading to an increase in ozone, but the CMAQ simulation suggests that the GCT does not have a significant impact on ozone concentrations outside of a few kilometers of the terminal boundary.

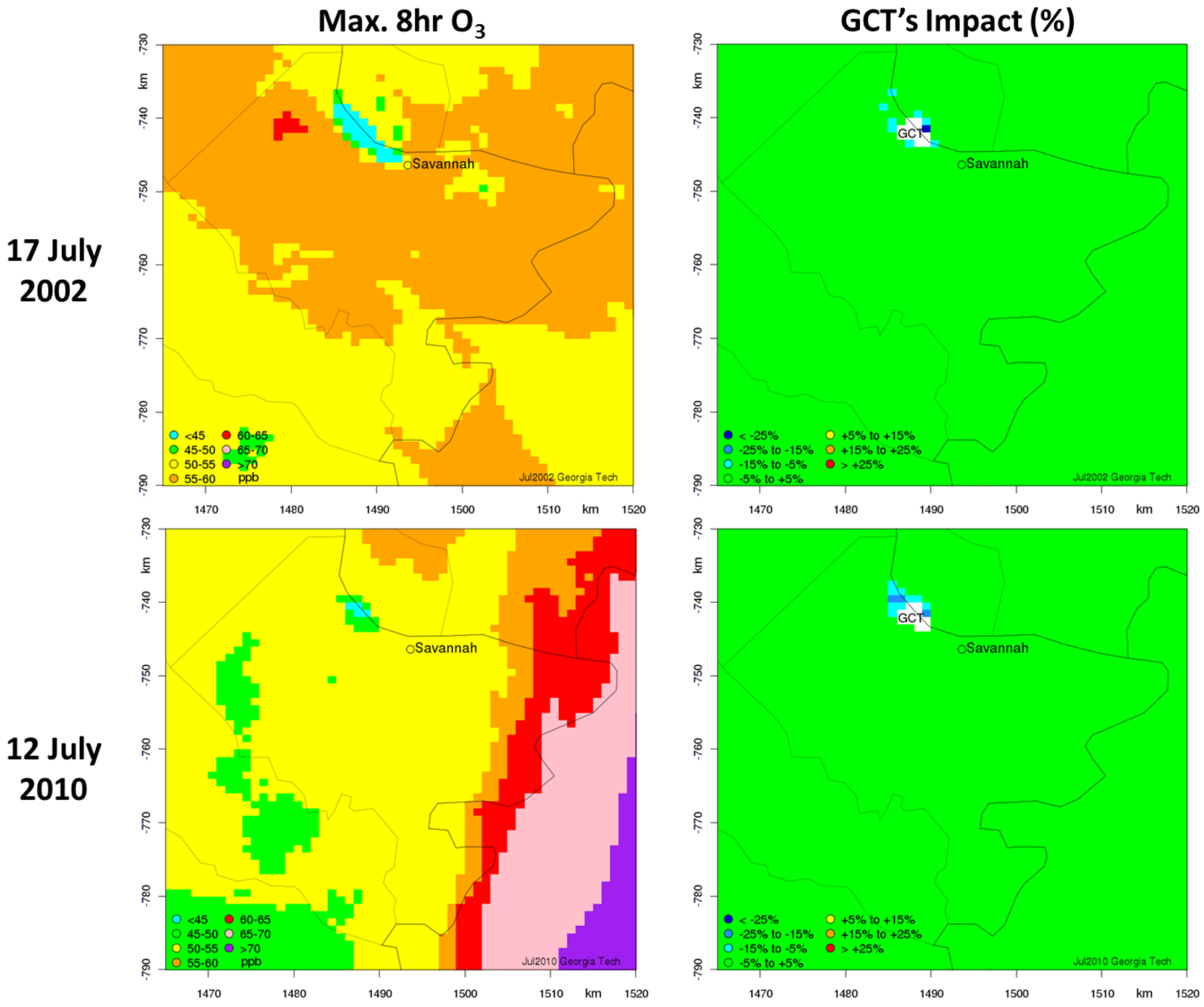


Figure 4. CMAQ simulated maximum daily 8-hour ozone concentrations in Chatham County on 17 July 2002 and 12 July 2010; and % contribution of the GCT (white blocks) to the surrounding areas' maximum daily 8-hour ozone concentrations.

Figure 5 shows similar results from the CMAQ model for PM2.5 air quality on 17 July 2002 and 12 July 2010. Once again, these were the days from the 2002 and 2010 modeled episodes in which the GCT impacts on the surrounding area's air quality were greatest. In the 2002 episode, the highest concentrations of PM2.5 were simulated to occur in the highly urban core of Savannah along the riverfront extending from the GCT to ~10km eastward (top left panel), and the GCT contributed as much as 15% to 25% of the pollutant load within ~5km of the terminal (top right panel). In the 2010 episode, overall simulated pollutant concentrations were much lower across the region (less than 5 μg/m^3, lower left panel), but the relative contribution of the GCT to the particulate loading that was present exceeded 25% in the immediate vicinity of the terminal and whose impact extended further across the region (lower right panel).

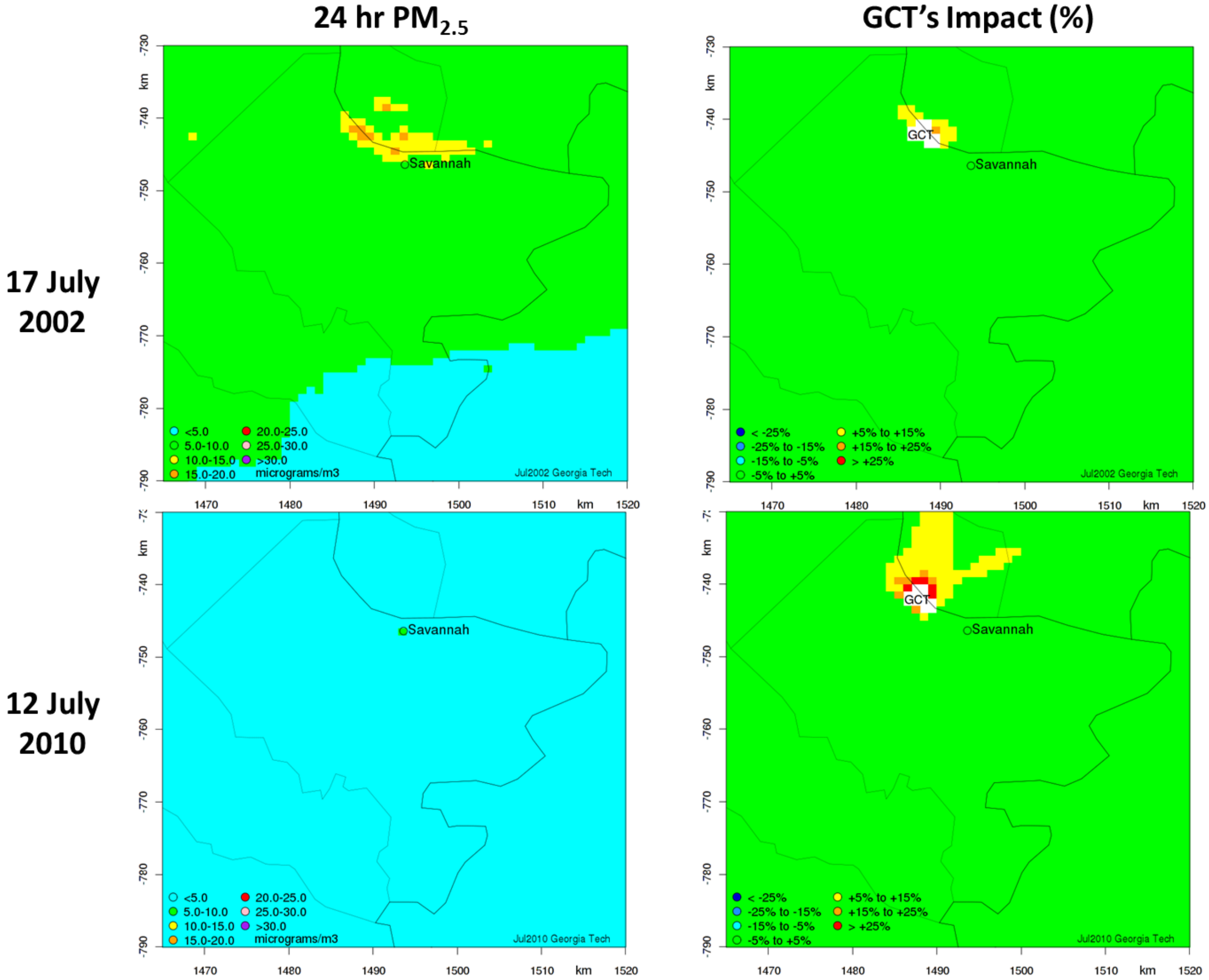


Figure 5. CMAQ simulated 24-hour average PM2.5 concentrations in Chatham County on 17 July 2002 and 12 July 2010; and % contribution of the GCT (white blocks) to the surrounding areas' PM2.5 pollutant load.

Resolving further, Figure 6 shows only the effect of the GCT's cargo handling equipment on ozone (upper left panel) and PM2.5 air quality concentrations (lower left panel) on 17 July 2002. These impacts are shown in contrast with the pollutants and pollutant precursors from all on-road mobile sources in the Savannah metro area (upper and lower panels on the right). Cargo handling equipment is particularly interesting because it is the one category of emissions that the GPA can most directly control. Despite the concentration of emissions and the visibility of cargo and its handling at the GCT, however, the CMAQ modeling results suggest that this source of emissions is a minor contributor to the greater region's overall air quality.

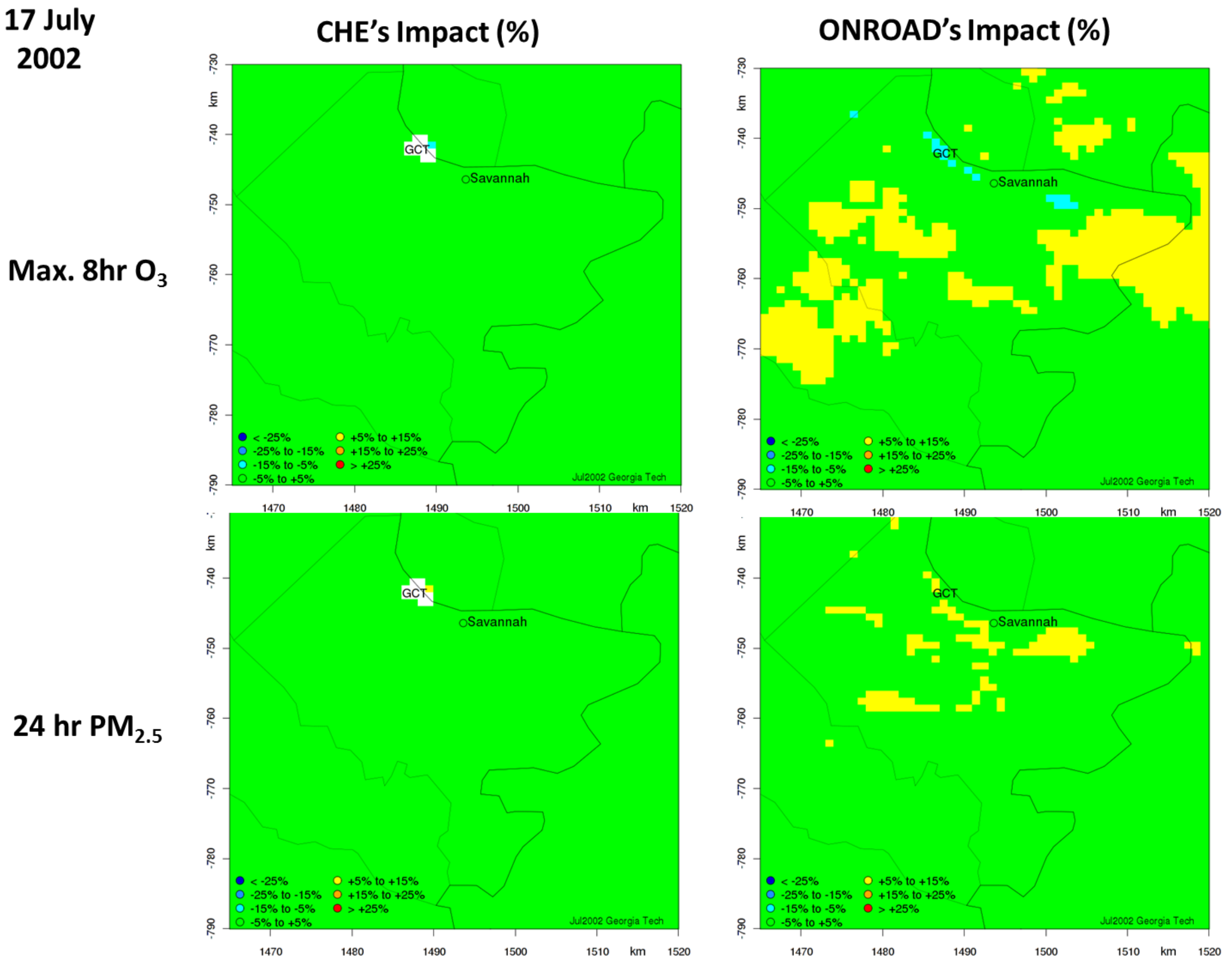


Figure 6. Percent contribution of emissions from the Garden City Terminal's cargo handling equipment and the Savannah metro area's on-road mobile sources to ozone and PM2.5 air pollutant loads on 17 July 2002.

Noting then that the impacts of the GCT on air quality are largely constrained to the area immediately adjacent to the terminal, the CMAQ modeling results were compared to the CALPUFF modeling results. Recall that CALPUFF cannot simulate the chemical transformation of pollutants so it is not useful for simulating ozone, which is formed via photochemical reactions from other precursor emissions (NOx and VOCs). It is useful for simulating the transport of pollutants that are emitted directly, however, such as PM2.5. Figure 7 shows simulated concentrations of PM2.5 resulting from only emissions from the GCT. Qualitatively, the CALPUFF simulation suggests that the impact from the GCT could be much larger than the CMAQ simulation initially indicated. Quantitatively comparing the results of the two simulations directly for both the 2002 and 2010 episodes, as shown in Figure 8, suggests that the impact could be as much as 3X greater. It should be noted, however, that even as CALPUFF suggests that the impact of the GCT could be higher than the CMAQ model indicates, absolute PM2.5 concentrations in most areas affected by the GCT are well below the daily National Ambient Air Quality Standard for PM2.5 of 35 $\mu g/m^3$.

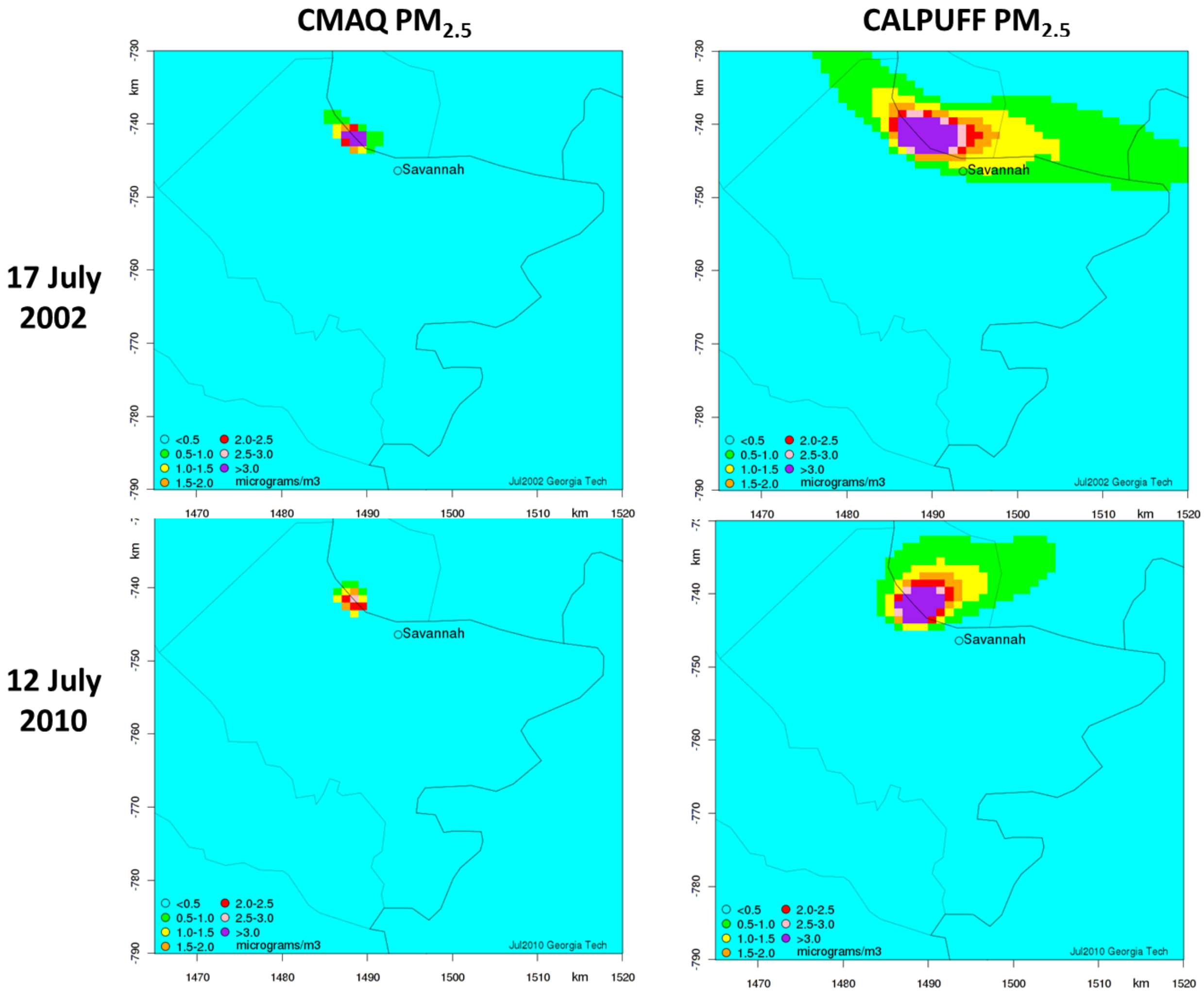


Figure 7. CMAQ (left) and CALPUFF (right) simulated 24-hour average PM2.5 concentrations in Chatham County on 17 July 2002 and 12 July 2010 resulting from emissions only at GCT.

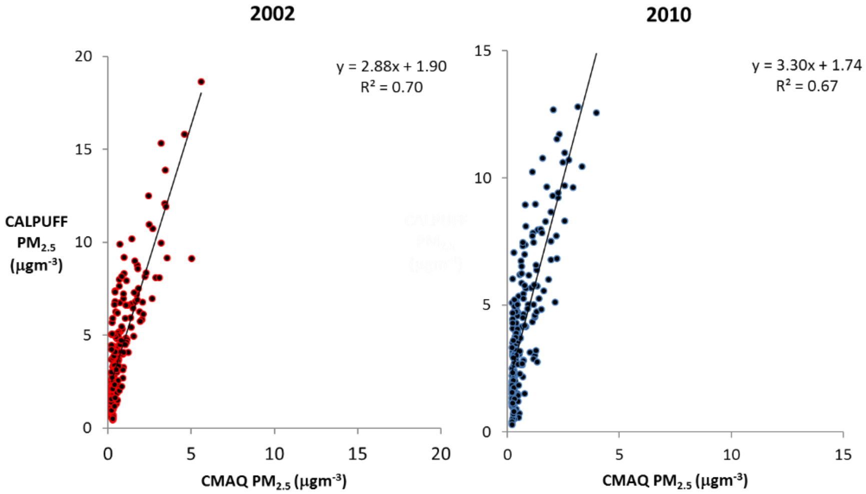


Figure 8. Direct comparison of CALPUFF and CMAQ simulated 24-hour average PM2.5 concentrations for the 2002 and 2010 episodes.

CONCLUSIONS:

In this study, a detailed emissions inventory was developed for Georgia’s Port of Savannah Garden City Terminal (GCT). Emissions were estimated for nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), coarse particulate matter (PM10), fine particulate matter (PM2.5), sulfur dioxide (SO_2) and ammonia (NH_3) for one 10-day period in July 2002 and another 10-day period on July 2010. The emissions were estimated using activity records provided by the Georgia Port Authority for vessel calls, equipment usage, and containers moved, and supplemental data gathered from engine manufacturers, previously published fuel studies, and the scientific literature regarding emission rates.

The number of containers moved (TEU) during the 10-day period in 2010 was 146% higher than the number of containers moved during the 10-day period in 2002. Despite this increase in port activity, the emissions of particulate matter, both coarse and fine, was 10% lower in 2010 than in 2002. SO_2 emissions decreased 85% in 2010 from the 2002 base. Emissions of NOx, VOCs, CO, and NH_3 all increased (36%, 61%, 70%, and 117% respectively from 2002 to 2010), but at rates less than the increase in container throughput. That is, for each container moved through the GCT, the emissions related to handling one container were less in 2010 than in 2002 for all pollutants.

Resolving the emissions by source category (Vessels, Tugs, Cargo Handling Equipment, Trucks, and Locomotives) revealed that the emissions per TEU differences between 2002 and 2010 were not uniform across all GCT operations. The largest decreases occurred in the vessels and tugs categories. This is because in 2010 bigger vessels delivered more TEUs per call, all the vessels and tugs used cleaner fuels, and some of them were equipped with newer engines that included modern emissions control technologies. The largest increases occurred from on-road trucks. This was not because trucks in 2010 emitted more per mile driven than trucks in 2002 (their emission rates were about the same during the two periods). Instead the reason for the increase of emissions from the truck sector occurred because of a transportation mode shift in moving containers. Relative to 2002, more containers were moved in and out of the GCT by truck than by locomotive – consequently, emissions from locomotives decreased as locomotive activity did not change in proportion to the increase in TEU moves. Lastly, the 2010 reduction in emissions per TEU for cargo handling equipment can be attributed to electrification of some equipment (particularly ship-to-shore cranes between 2002 and 2010), the replacement of older equipment with new engines outfitted with emissions control technologies, the introduction of low sulfur fuel, and increased fuel efficiency resulting from the use of a fuel additive.

The emissions estimates were used to drive an advanced 3-D photochemical-transport computer model to simulate air quality in the Savannah metro area. Overall the model results suggest that impacts from the GCT are less than 5 ppb for ground-level ozone within a radius of 10 km of the terminal, with ozone scavenging (reduction) being the dominate impact nearby, and less than 2 $\mu g/m^3$ increase for PM2.5 within a radius of 5 km. An alternative air quality model suggested that the PM2.5 impacts could be 3X larger in both spatial extent and concentration, but overall concentrations remain far below the federal daily standard for particle pollution.