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C-PORT: A COMMUNITY-SCALE NEAR-SOURCE AIR QUALITY SYSTEM TO ASSESS PORT-RELATED AIR QUALITY IMPACTS

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Abstract: With increasing activity in global trade, there has been increased activity in transportation by rail, road and ships to move cargo. Based upon multiple near-road and near-source monitoring studies, both busy roadways and large emission source at the ports may impact local air quality within several hundred meters of the ports. As the volume of trucking and freight movement increases, near-road air quality along transportation routes could be affected well outside port boundaries. Port expansion also could include changes in emissions from the port itself, as additional resources are added to account for the potential increase in freight, which could affect air quality in bordering communities. Health effects have been associated with near-road exposures and proximity to large emission sources, so characterizing emission sources is important for understanding potential health effects. To address this need, we have developed a new community-scale tool called C-PORT to model emissions related to all port-related activities – including, but not limited to ships, trucks, cranes, etc. – and predict concentrations at fine spatial scales in the near-source environment. While the long-term objective is to make this web-enabled tool for easily studying air quality and exposure related to ports at any U.S. port, the initial development is focusing on the Port of Charleston in South Carolina, USA, to complement a field-study that was conducted during Spring 2014 to take air quality measurements in residential neighborhoods in the port vicinity. The C-PORT modeling system includes reduced-form approaches to model dispersion of area, point, and line sources related to port activities, and emissions and activity information from the Port of Charleston. The use of the reduced-form approach to model port-related activities in C-PORT enables us to examine what-if scenarios of changes in emission volume, such as due to changes in traffic counts, fleet mix, speed, or in port emissions due to equipment or vehicles in near real-time. The C-PORT model can be used to examine different scenarios of air quality impacts in order to identify potentially at-risk populations located near emission sources, and the effects that port expansion may have on them. We will present the C-PORT modeling system prototype for the Charleston port, and highlight the benefits of such a screening-level tool with illustrative examples, and associated challenges for expanding C-PORT to model other U.S. ports.

Key words: Port emissions, Freight, Dispersion Modeling, Air pollution, Exposure.

INTRODUCTION

As has been established in near-road and near-source monitoring studies, busy roadways and large emission sources may impact local air quality within several hundred meters of the source. A recent study showed that 19% of the U.S. population live near high traffic volume roads, and are thus exposed to traffic-related pollution (Rowangould, 2013). A significant portion of this traffic is related to the freight transportation system that moves nearly 37 million Twenty-foot Equivalent Units (TEUs) with heavy-duty diesel trucks. These trucks, in addition to the large commercial marine vessels that transport these goods in and out of ports are a significant source of pollution in the immediate vicinity of the port. The effects of port expansion extend beyond the borders of the port. Port expansion also could include changes in emissions from the port itself, as additional resources are added to account for the potential increase in freight, which could affect air quality in bordering communities. As the volume of trucking and freight movement increases, near-road air quality along transportation routes could be affected well outside port boundaries. Health effects have been associated with near-road exposures and proximity to large emission sources, so characterizing emission sources is important for understanding potential health effects. An analysis of 43 marine ports in the U.S. showed that some of these ports have a large population of low-income households and minorities that live in the immediate vicinity that raises potential environmental justice related concerns. (Rosenbaum et al, 2011). Several regulatory programs are being put in place by the U.S. EPA to address exposures related to port-related sources. Norsworthy et al (2011) showed the impacts of voluntary clean truck programs at three U.S. ports in reducing adverse exposures. However, there is a lack of tools that can be applied to study near-source pollution in an easy manner, and explore the benefits of improvements to air quality and exposures – either due to voluntary or mandatory programs. Screening-level or reduced-form air quality modeling is a useful tool for examining what-if scenarios of changes in emission volume, such as those due to changes in traffic counts, fleet mix, or speed, or changes in port emissions due to equipment or vehicles. Examining various scenarios of air quality impacts in this way can identify potentially at-risk populations located near emission sources, and the effects that port expansion may have on them. We present a modeling framework here called the Community modeling system for near-PORT (C-PORT) assessments that enables such a capability using a web-based front-end, and present an illustrative example. The C-PORT tool uses Google Earth, PostGIS and PostgreSQL – all open source software components – along with reduced-form models to integrate various national-scale input information to provide concentration estimates.

APPROACH

Port-related activities involve multiple emissions sources both within and outside the terminal. Inside the terminal, the various sources are trucks and rubber tire gantry (RTG) cranes which are modeled as area sources; ships that are docked at the terminals, which are modeled as point sources. Outside the terminals, the various sources are: ships that are in transit to the terminals, which are modeled as buoyant line sources; onroad vehicles that are related to the ports, which are modeled as line sources, and rail traffic that are related to the ports, which are also modeled as line sources.

To develop C-PORT, we initially selected the Port of Charleston in South Carolina, U.S. as the candidate port for the project. The development phase involved using Charleston as a test-bed where both detailed [such as AERMOD (Cimorelli, 2005) and R-LINE (Snyder et al, 2013)] and reduced-form models will be applied to model the various port-related sources, and then the lessons learned will be leveraged to scale the effort to include all ports in the EPA's Region 4 states. This included 17 different sea-ports situated along the Gulf Coast of Mexico and the Southeastern U.S. The C-PORT system runs on an interactive website, and uses emissions inputs for these 17 seaports and applies reduced-form modeling approaches to model dispersion at very highly resolved spatial scales around the port areas. The system allows the user to assess the impacts of what-if scenarios, where various inputs can be changed for each source type, and predict changes in concentrations.

We use a reduced-form approach to model area sources (for terminal activities), line sources (for on-road mobile), buoyant line sources (for ships in transit), and point sources (for ships at terminal). These algorithms use approximations to eliminate iterations used by other models to find effective and profiled dispersion and meteorological parameters. In most cases, these approximations lead to a conservative estimation of ground-level concentrations. Many simplifications used in these approximations are based on the receptors being at or near ground level, and complex terrain is not considered. We developed an initial set of source configurations for which AERMOD and the reduced-form models were applied, and iteratively improved the reduced-form models to obtain reasonable results (generally +/- 10 to 20%) when compared to AERMOD.

RESULTS AND DISCUSSION

For initial assessment, model simulations for the Charleston port were conducted using the AERMOD (Cimorelli et al, 2005) model in three scenarios. The pollutants of interest were CO, NO_x, $PM_{2.5}$, Diesel PM, SO_2, Benzene, $EC_{2.5}$ and $OC_{2.5}$. In the first scenario, we used default inputs from EPA's National Emissions Inventory (NEI) for the year 2008 to model the impacts of five terminals in the Charleston port. In NEI, terminal-related activities are reported as county-level emissions, while ships at ports are represented as point sources. Underway emissions from ships are represented as a limited number of points. We assigned county-level emissions estimates of terminal activity-related sources to the 5 terminals using an area-weighting approach. In the second scenario, we used terminal activity information from the local port authority [South Carolina State Port Authority (SCSPA)] as a surrogate to distribute the emissions between the terminals. In the third scenario, we used entirely local information from

SCSPA, i.e., both emissions information and terminal activity were based on SCSPA inputs. Further, we used detailed mapping of ships in the harbour channel using data from the ORNL/Vanderbilt/U.S. Army Corps of Engineers National Waterway Network (http://www.navigationdatacenter.us/data/datanwn.htm), and merged it with the National Waterway Network (NWN) Link Commodity Data (http://www.navigationdatacenter.us/data/datalink.htm) to determine channels that had shipping activity. We used ArcGIS to create a new point layer file and added points every 500 m along each segment from the start-point or end-point (depending on the orientation of the line segment with regard to the terminals) of the lines longer than about 600 m. The latter dataset was then used to model underway emissions in AERMOD using three different approaches – a series of point sources, area sources and volume sources. Figure 1 shows the original location of ships at terminal (green circle), ships underway (6 black circles), and the new 500m spaced points developed by us using the data described above. We further assigned emissions from the single green circle at the mouth of the harbour to 5 points that are closer to the terminal, to more accurately represent the terminal-related shipping activity. This approach for assigning underway emissions from ships illustrates potential improvements that the C-PORT tool is capable of while augmenting national-scale default inputs (from NEI) with improved source characterization spatially for performing local-scale assessments.

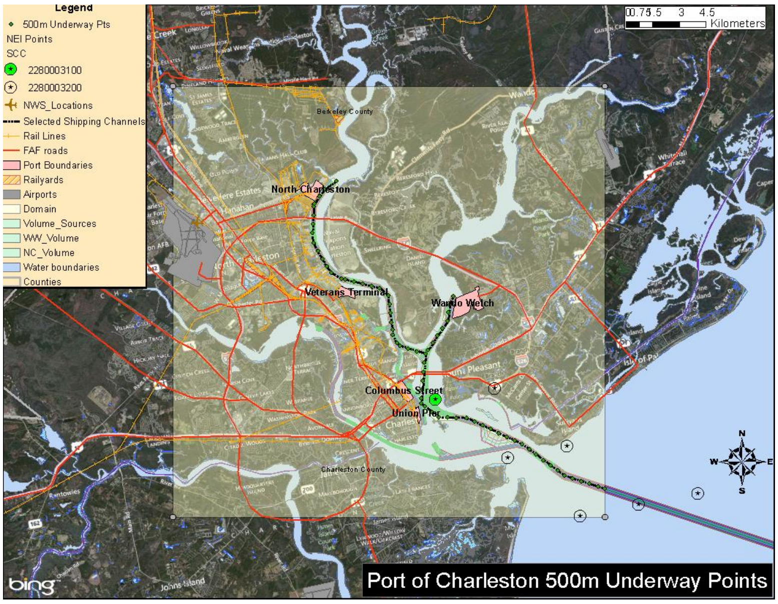

Figure 1. The modeling domain for the Port of Charleston, showing the 5 terminal areas, location of shipping lanes and ships in NEI vs. new spatial allocation developed for this modeling.

The on-road mobile sources were modeled for the entire county in which the Charleston port was located using the R-LINE model. RLINE is a research-level, line-source dispersion model developed as a part of EPA's on-going efforts to further develop tools for a comprehensive evaluation of air quality impacts in the near-road environment. The required information for calculating the emission rate was gathered from multiple sources. The roadway information including road coordinates, road type, and annual average daily traffic (AADT) was from Federal Highway Administration's (FHWA) Freight Analysis Framework Version 3 (FAF3) (FHWA, 2012). The roadway information provided in FAF3 contains curved and long road segments. Since RLINE assumes each road to be a straight line, we split the original roadways into several segments with starting and end points at the vertices of the roadway. The emissions factors were based upon outputs from EPA's Motor Vehicle Emissions Simulator (MOVES) modeling system (MOVES 2010b) for January and July 2010. The emission factors were grouped based on road type (12 categories), vehicle speed (16 bins), ambient temperature (binned in intervals of 5 degrees Fahrenheit from 0 - 100), and vehicle type (8). To further break down the AADT into the 8 vehicle types, we used data from FHWA's Highway Statistics to obtain the fraction of 6 Highway Performance Monitoring System (HPMS) vehicle classes. The HPMS class was then converted based on EPA's Emission

Inventory Improvement Program to MOVES vehicle type. The AADT was then distributed based on the fraction to obtain the traffic count for each vehicle type. The vehicle speed was from the MOVES input file, which contains county-based vehicle speed grouped by road type and vehicle type.

The meteorological inputs were generated using the AERMET processor, and using the National Weather Station (NWS) in Charleston. For the AERMOD modeling, we created three sets of receptors for a domain that was 24.1 x 24.1 km square centered on the Port – a uniform grid at a resolution of 90m (72,900 receptors), census block centroids (6,766) and census block group centroids (165) – for which AERMOD was instrumented to predict hourly as well as annual average concentrations. We assessed AERMOD model outputs from each of these three simulations, and assessed the incremental benefits of using local scale information at the port level, instead of national defaults from EPA's NEI for assessing near-port impacts. We then proceeded to implement and test the reduced-form models on the C-PORT modeling system for the 17 seaports.

C-PORT is designed to model hourly concentrations for a chosen hour (summer vs. winter season and time of day) and meteorological condition (based upon atmospheric stability), as well as annual averages for a set of receptors that are chosen 'on the fly' based upon the chosen spatial extent on the web-browser, such that the minimum spatial resolution is at least 30m. For computing annual averages, we developed an algorithm to explicitly model only 100 representative hours that span range of meteorological conditions that affect dispersion (wind speed, wind direction and atmospheric stability), and then use weights that take into account the frequency of these conditions in the observed hourly meteorological data during the year. Overall, the design constraints necessitated that the model is able to run in the order of seconds to minutes, and provide visual display of concentrations for the chosen areal extent. Figure 2 shows a screenshot from the C-PORT modeling framework, focusing on onroad emissions in the Charleston area. It shows baseline concentrations around the major roadways, and a panel with fields enabled to select road-links as well as change inputs including fleet mix, AADT, etc.

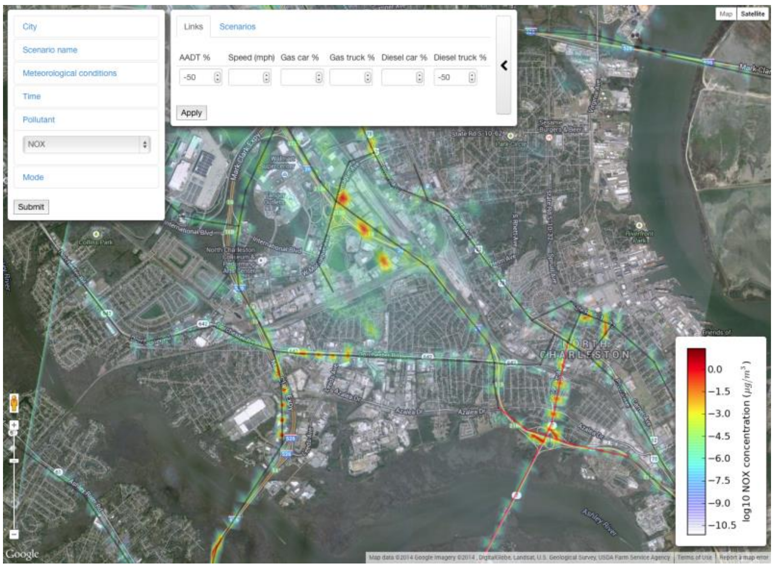

Figure 2. Screen shot of C-PORT showing ability to choose road-links on demand (highlighted in red), and changing fleet activity.

CONCLUSIONS

We have developed a community-scale assessment tool called C-PORT, with initial testing for the Port of Charleston, and then scaled to 17 sea-por9ts in the Southeastern U.S. states. The initial implementation of the modeling system for the Port of Charleston helped in assessing the impacts of using national-scale inputs (such as from NEI) versus those from local sources (such as from SCSPA), and compare/contrast the strengths and weaknesses of the two approaches. Furthermore, comparing model outputs from AERMOD versus reduced-form models also helped with improving the algorithms, while still keeping them computationally efficient for a web-based implementation. On-going efforts will compare the C-PORT predicted concentrations with the monitoring data from Spring 2014. While the modeling tool is currently designed to use national-scale emissions and activity inputs, future enhancements would enable use of local-scale data when available on-demand. A significant capability of the tool is to provide an easy-to-use GUI that can be used by community planners to assess air quality impacts of 'what if' scenarios that can be used for planning a sustainable development at community scales. These scenarios help plan potential growth in port activities (increased ships, trucks, etc.), assess impacts of improved energy efficiency in port terminal area activities (such as electrification of RTGs), reduction in emissions due to regulatory programs related to commercial marine vessels, rail, trucks (low Sulfur fuel), etc. Future enhancements to C-PORT include adding the capability to estimate health risk due to air quality exposures for multiple pollutants at community scales, add new source information and to model any U.S. port on demand.

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