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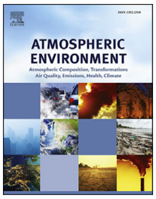

Characterizing spatial variability of air pollution from vehicle traffic around the Houston Ship Channel area

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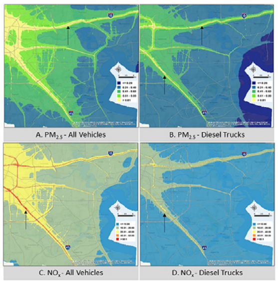
HIGHLIGHTS

- Heavy-duty vehicles were the largest contributor of traffic-related $PM_{2.5}$ concentrations in the Houston Ship Channel area.
- Highest concentrations of traffic-related $PM_{2.5}$ and NO_x occurred in winter.
- Concentrations of traffic-related $PM_{2.5}$ and NO_x decreased by nearly 40% within 500 meters of major roads.

GRAPHICAL ABSTRACT



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ABSTRACT

Mobile emissions are a major source of urban air pollution and have been associated with a variety of adverse health outcomes. The Houston Ship Channel area is the home of a large number of diesel-powered vehicles emitting fine particulate matter ($PM_{2.5}$; ≤ 2.5 μm in aerodynamic diameter) and nitrogen oxides (NO_x). However, the spatial variability of traffic-related air pollutants in the Houston Ship Channel area has rarely been investigated. The objective of this study is to characterize spatial variability of $PM_{2.5}$ and NO_x concentrations attributable to on-road traffic in the Houston Ship Channel area in the year of 2011. We extracted the road network from the Texas Department of Transportation Road Inventory, and calculated emission rates using the Motor Vehicle Emission Simulator version 2014a (MOVES2014a). These parameters and preprocessed meteorological parameters were entered into a Research LINE-source Dispersion Model (RLINE) to conduct a simulation. Receptors were placed at 50 m resolution within 300 m to major roads and at 150 m resolution in the rest of the area. Our findings include that traffic-related $PM_{2.5}$ were mainly emitted from trucks, while traffic-related NO_x were emitted from both trucks and cars. The traffic contributed 0.90 $\mu g/m^3$ $PM_{2.5}$ and 29.23 $\mu g/m^3$ NO_x to the annual average mass concentrations of on-road air pollution, and the concentrations of the two pollutants decreased by nearly 40% within 500 m distance to major roads. The pollution level of traffic-related $PM_{2.5}$ and NO_x was higher in winter than those in the other three seasons. The Houston Ship Channel has earlier morning peak hours and relative late afternoon hours, which indicates the influence

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of goods movement from port activity. The varied near-road gradients illustrate that proximities to major roads are not an accurate surrogate of traffic-related air pollution.

1. Introduction

The Houston Ship Channel Area has numerous sources of air pollution, including intensive road networks, refinery facilities, and ships from adjacent ports. It is extended from the Port of Houston, whose foreign waterborne tonnage ranks first place and total tonnage ranks second place among all U.S. ports (Port of Houston Authority, 2016), to Downtown Houston, including the largest petrochemical complex in the U.S. (Sexton et al., 2007). In U.S., the health concerns of traffic-related air pollution are estimated to mount given the growing projections, expanding road networks, and increasing congestion related to freight transportation and goods movements in recent decades (U.S. Department of Transportation, 2015). The air quality of the Houston Ship Channel and its surrounding area, however, yields a long-term environmental health concern. For example, by the year of 2016, the Houston-Galveston-Brazoria area, where the Houston Ship Channel located, was still failed to attain the federal health-based ozone standard set by the U.S. Environmental Protection Agency (EPA) (EPA, 2016). In addition to high levels of ozone, the Houston Ship Channel's non-stop transportation activities are powered by numerous gasoline and diesel engines that emit airborne pollutants such as particulate matter less than 2.5 μm in aerodynamic diameters ($PM_{2.5}$) and nitrogen oxides (NO_x), known to contribute to adverse health outcomes among people working or living in nearby places (HEI, 2010).

Limited studies have examined traffic-related air pollution in areas like the Houston Ship Channel, where there is a high density of goods movements and diesel trucks. Kozawa et al. (2009) measured near-road pollutants using an electric vehicle equipped with a series of air analyzers while running in communities adjacent to ports of Los Angeles and Long Beach. They found that the concentration of multiple air pollutants (PM, black carbon, NO_x, and others) increased to five times at the downwind sites of freeways and two times at the downwind sites of arterial roads. Another mobile sampling study was conducted in the Port of Oakland, CA (Dallmann et al., 2011), which reported a 54% reduction of airborne black carbon after the implementation of truck retrofit/replacement rule. Wu et al. (2009) used the California Line Source Dispersion Model version 4 (CALINE4) to evaluate spatial variability of traffic-related $PM_{2.5}$ and elemental carbon in the ports of Los Angeles and Long Beach. In their results, light-duty vehicles were found to have contributed 61% of traffic-related $PM_{2.5}$, which was significantly higher than the contribution of heavy-duty trucks (39%). However, their study was based on the presumption that the proportion of heavy-duty trucks was assigned based on roads types. So this study has been unable to account for the variability of traffic composition in simulations. In the perspective of economy, Lee et al. (2012) estimated the healthcare cost saved from reduced air pollution by implementing a Clean Truck Program (CTP) in a corridor of the ports of Los Angeles and Long Beach. The reduction of traffic-related air pollution was calculated from the California Puff (CALPUFF) model. It was estimated that healthcare costs of $440 million from drayage truck emissions in the baseline year 2005 could decrease by 96% in the seventh year after implementing the CTP. Hence, the saved health costs could exceed the costs of replacing 10,000 old drayage trucks running in that corridor within 4 years.

Although near one of the largest marine ports in this country, traffic-related air pollution in the Houston Ship Channel has not been fully investigated. Therefore, the purpose of our study is to characterize the spatial variability of traffic-related air pollutants at fine-scale resolution in the Houston Ship Channel and its surrounding area. A dispersion modeling study is conducted to estimate the concentrations of $PM_{2.5}$ and NO_x attributable to traffic at high spatial and temporal resolution using traffic data, meteorological data, and vehicle emission estimates.

2. Methods

The most recent version (v1.2) of Research LINE-source Dispersion Model (RLINE) is used to model the concentrations of traffic-related air pollution in the Houston Ship Channel area (Fig. 1). RLINE is a dispersion model based on a steady-state Gaussian formulation (EPA, 2013; Snyder et al., 2013), and it is designed to simulate the physical dispersion of inert air pollutants from line-source emissions. It takes the inputs of traffic activities, vehicle emission rates and meteorology conditions, and then calculates the concentrations of traffic-related air pollution deposited on “receptors”, which is a series of point locations or intersections of continuous grids placed in study area.

2.1. Study area

The Houston Ship Channel is located to the east of the city of Houston, having approximately 80 km extension from the Port of Houston and linking the Downtown Houston area to the Gulf of Mexico (Suarez et al., 2006). We estimated the mass concentrations of traffic-related $PM_{2.5}$ and NO_x within a 40 km × 40 km study area (Fig. 1), which covers the entire Houston Ship Channel, marine ports, residential neighborhoods, commercial places, and industrial facilities. A large population is involved and several neighborhoods near the Houston Ship Channel have high poverty rates.

2.2. Traffic activity

The Roadway Inventory shapefile obtained from the Texas Department of Transportation (TxDOT) (http://www.txdot.gov/inside-txdot/division/transportation-planning/roadway-inventory.html) includes segment-specific Annual Average Daily Traffic (AADT) counts, proportions of trucks, and other characteristics of the roads monitored by the Highway Performance Monitoring System (HPMS) in the state of Texas. Due to the dispersion of pollutants, the roads located outside but within a 25 km extension of the study area were also included as the emission sources. Combined with the roads located inside the study area, 9673 segments of roads in total were extracted from the TxDOT's Roadway Inventory shapefile. The road segments are distributed across six Texas counties, Harris, Brazoria, Fort Bend, Galveston, Chambers, and Liberty. The road segments with at least 4 lanes are shown as grey lines in Fig. 1.

The Average Daily Vehicle Volume (ADV) of each road segment was calculated from the AADT counts and the Vehicle Classification Fraction (VCF). AADT was generated from the total number of