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Modeling spatial variations of black carbon particles in an urban highway-buildings environment

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Abstract

Highway-building environments are prevalent in metropolitan areas. This paper presents our findings in investigating pollutant transport in a highway-building environment by combining field measurement and numerical simulations. We employ and improve the Comprehensive Turbulent Aerosol Dynamics and Gas Chemistry (CTAG) model to simulate the spatial variations of black carbon (BC) concentrations near highway I-87 and an urban school in the South Bronx, New York. The results of CTAG simulations are evaluated against and agree adequately with the measurements of wind speed, wind directions and BC concentrations. Our analysis suggests that the BC concentration at the measurement point of the urban school could decrease by 43–54% if roadside buildings were absent. Furthermore, we characterize two generalized conditions in a highway-building environment, i.e., *highway-building canyon* and *highway viaduct-building*. The former refers to the canyon between solid highway embankment and roadside buildings, where the spatial profiles of BC depend on the equivalent canyon aspect ratio and flow recirculation. The latter refers to the area between a highway viaduct (i.e., elevated highway with open space underneath) and roadside buildings, where strong flow recirculation is absent and the spatial profiles of BC are determined by the relative heights of the highway and buildings. The two configurations may occur at different locations or in the same location with different wind directions when highway geometry is complex. Our study demonstrates the importance of incorporating highway-building interaction into the assessment of human exposure to near-road air pollution. It also calls for active roles of building and highway designs in mitigating near-road exposure of urban population.

Keywords

Near-road air pollution; CFD; air quality; human exposure

1. Introduction

In recent years, epidemiological and toxicological studies worldwide have suggested an association between human exposure to traffic-related air pollutants and a range of adverse respiratory and cardiovascular health effects.¹ Many near-road air quality studies have

characterized open highway conditions, i.e., large roads without any major structures in the close vicinity.²⁻⁴ Nevertheless, the presence of buildings near highways, referred to here as the highway-building environment, is common in urban areas. In a highway-building environment, roadway configuration and building geometry both affect the flow, which differs from a street canyon environment, where buildings dominate the overall flow.

Thus, in order to accurately assess human exposure to traffic-related air pollutants in the highway-building environments, we need to address the following two questions: 1) How do buildings affect the transport and transformation of traffic-related air pollutants near roadways? And 2) What are the horizontal and vertical profiles of traffic-related air pollutants near building surfaces? This paper represents the first effort to answer those two questions. We applied and improved the Comprehensive Turbulent Aerosol Dynamics and Gas Chemistry (CTAG) model to simulate the spatial variation of near-road black carbon (BC) concentration in a highway-building environment near highway I-87 in the South Bronx, NY, and compared the modeling results with the measurements conducted by Patel and coworkers in 2004.⁵

Among the five boroughs of NYC, the Bronx has ranked highest in both asthma hospitalizations and deaths in recent years. Between 1990 and 2000, the asthma rates decreased only 3% in the Bronx, as compared to 39% and 35% reduction in Brooklyn and Manhattan during the same period according to New York City Department of Health and Mental Hygiene.⁶ Although the origin of asthma is multi-factorial, recent studies link asthma to exposure to diesel particulate matter from heavy-duty diesel traffic in the area.⁷⁻⁹ It is estimated that 66% of the population in the Bronx is living within 150m of major roads, including interstate, state, and county highways, access ramps, and arterials, and 91% within 300m.¹⁰ BC particles are not only a tracer of diesel traffic, but are also associated with cardiopulmonary health effects.¹¹⁻¹⁴ As BC particles cause a direct positive radiative acting as a short lived climate forcer, control measures of particulate matter (PM) emissions that lead to reduction of the BC component will likely have a positive impact on human health, resulting in a co-benefit of PM reductions.

This paper is organized as follows. We start with a description of our numerical modeling approach, followed by a brief introduction of the field measurement. Then, we compare the predicted and measured wind speed, wind direction, and BC concentrations at the sampling site. Next, we elaborate on how highway configurations and buildings affect the spatial variation of BC concentrations based on our numerical simulations. Finally, we discuss the implications of our study in terms of human exposure assessment and highway design.

2. BC Properties, Field Measurements and Simulated Cases

In this study, black carbon is defined as the primary constituent of PM_{2.5} that is responsible for light absorption of particles in the atmosphere.¹⁵ We model BC particles as inert species, which experiences no chemical transformation within the timescale of concern (seconds to minutes). Because most BC occurs as sub-micron particles, they are expected to adopt the flow velocity very quickly (i.e., with small Stokes number), it is reasonable to assume that they will disperse like gaseous species.^{13,14} Due to their relatively low concentrations, we further assume that BC particles do not affect the turbulent flow in the atmosphere.¹⁶

A detailed description of the field measurements was provided by Patel and coworkers.⁵ A brief summary is presented here. The field measurements were conducted in an urban school, referred as U2, in the South Bronx, from February to March, 2004. U2 is located approximately 30m east of I-87, a highway with annual average daily traffic of 85,000 vehicles. BC concentrations were collected using a dual-beam Aethalometer (Model AE-21, Magee Scientific, Berkeley, CA) operated at 4 LPM and using a size selective cyclone for

PM_{2.5} (KTL cyclone, BGI, Waltham, MA). The unit was placed in an empty classroom with the sampling inlet located 0.9 m outside from the school wall, and the sampling inlet was protected from rain with a stainless steel rainhat. Thus the BC concentrations were measured at a fixed height and a fixed distance from I-87. A weather station (Vantage Pro Model 6150C, Davis Instrument Corp., Hayward, CA) was installed on the school rooftop to monitor and record temperature, relative humidity, barometric pressure, wind speed and direction, and precipitation. At U2, traffic data were collected using a video camera adjacent to highway. Vehicles counts were obtained manually by watching daytime videos. Two categories of vehicles are counted: Category I, mostly gasoline powered vehicles including passenger cars, vans, sport utility vehicles, pick-up trucks, and small double-axle trucks; and Category II, primarily diesel powered vehicles including large trucks with more than two axles, and buses.

As we are primarily interested in the effects of highway pollution on the nearby environment, we focus only on conditions with wind blowing from I-87 to the U2 site, i.e., with wind direction varying from south southwest (SSW or 202.5°) to north northwest (NNW or 337.5°). For the I-87 segment next to U2, some portion is elevated with solid embankment, while the other portion is elevated with open space (Figure 1). This complex geometry, combined with different wind directions, leads to distinctly different spatial distributions of BC in this highway-building environment (discussed in Section 4.2). As the measured BC concentrations are only available as hourly-averaged data, we selected 34 cases with stable wind and traffic conditions, modeled using steady-state simulations. These 34 cases represent different hours from 6 am to 4 pm between March 12th and 22nd, 2004, among which 14 cases were during morning rush hours. Details of wind directions/speed, traffic volumes, and BC emission rates are listed in Table S1 in the Supporting Information.

3. Modeling Method

The CTAG model simulates the transport and transformation of exhaust particles from points of emissions to ambient background.^{2–4} Figure S1 in the Supporting Information illustrates the structure and components of the CTAG model. The transport portion of the CTAG model is called CFD-VIT-RIT, which has been applied to study the effects of highway configuration on near-road air quality under the open highway conditions. VIT stands for vehicle induced turbulence, and RIT stands for road induced turbulence.² In this study, we expand the capability of CFD-VIT-RIT to simulate near-road air quality in highway-building environments. *ANSYS FLUENT 12.1* is employed as a turbulence solver for the CTAG model.¹⁷ We compared several turbulence models including standard k-epsilon, RNG k-epsilon, and realizable k-epsilon models, which shows that three models yield similar results (Figure S2). We selected the steady standard k-epsilon turbulence model as it has been demonstrated more computationally stable and less intensive for isothermal flow.¹⁸ Several user-defined functions (UDF) are created to simulate the highway-buildings environment.

3.1 Modeling Domain

The modeling domain for our study was chosen as an approximate 800m×800m×150m block in the South Bronx (Figure 1). It consists of highway I-87, a surface street, U2, several low-rise buildings, and a high-rise building about 45m tall. More details regarding the modeling domain can be found in the Supporting Information (Section S2).

3.2 Boundary conditions

The ambient wind and turbulence profiles representing the urban lower atmospheric boundary are created using surface meteorological measurement data recorded at La Guardia

Airport (6.4 km from the U2 site) and upper air data provided by the National Oceanic and Atmospheric Administration's Radiosonde Database. Detailed discussions on the boundary conditions can be found in the Supporting Information (Section S3).

3.3 BC Emission Rate and Emission Zone Modeling

The BC emission rates are estimated by the following procedures. First, the $PM_{2.5}$ emission factors reflecting the vehicle conditions in New York are obtained from the New York State Department of Transportation (NYSDOT). These emission factors were generated using the MOBILE6.2 and are required for microscale air quality analyses in NYSDOT projects.¹⁹ Second, $PM_{2.5}$ emission factor for each vehicle type is multiplied by its corresponding traffic volumes. The two vehicle types, Categories I and II (defined in Section 2), are further classified by vehicle type distribution from NYSDOT.¹⁹ Next, the relative fractions of BC in $PM_{2.5}$ emissions from mobile sources were obtained from SPECIATE (Version 4.0), USEPA's repository of particulate matter (PM) speciation profiles of air pollution sources. SPECIATE reports elemental carbon (EC) measurements rather than BC. EC is typically defined as refractory carbon by thermal/optical method, while BC is defined as light-absorbing carbon by optical methods.²⁰ Typically, BC optical and EC thermo-optical methods are highly correlated.^{21,22} A recent study by Yan et al showed a strong correlation between the two methods in New York City.²³ As there is no simple conversion factor between BC and EC, many studies assumed that BC and EC are equivalent, the same assumption adopted in this study.^{21,24,25} The average BC/ $PM_{2.5}$ fraction is 20% for Category I, and 65% for Category II, which are consistent with the findings from a number of experimental studies.^{20,26,27}

A uniformly mixed traffic emission zone was created by merging the turbulence zone on the surface of I-87. The height of the emission zone was estimated by the ratio of recorded traffic volume of Category I to Category II.³ VIT is generated by modeling real-shaped vehicles in a traffic stream based on the traffic volumes and the ratio of Category I to Category II. To estimate RIT, appropriate surface roughness lengths are selected for the highway surface and estimated temperature differences between highway surface and air is applied based on the weather data in New York.² Values of turbulent kinetic energy are then calculated due to velocity gradients.

3.4 Background BC Concentrations

The background BC concentrations for the modeling period are taken as the values of elemental carbon (EC) concentrations at the ambient air monitoring station operated by New York State Department of Environmental Conservation (NYSDEC), located at a New York City Intermediate School (IS 52), 681 Kelly Street off Prospect Avenue in the South Bronx.²⁸ With our assumption that EC and BC are equivalent, the daytime average BC concentration is estimated to be $0.64 \mu g m^{-3}$ for the corresponding period of the simulation.

4. Results

4.1 Model Evaluation

Our model is evaluated against measured wind speeds, wind directions and BC concentrations under three types of highway-building environments (i.e., highway-building canyon, highway viaduct-building and transitional condition, which will be elaborated in Section 4.2), respectively. The performance metrics include Mean Normalized Error (MNE), Mean Normalized Bias (MNB), Mean Fraction Error (MFE), and Mean Fraction Bias (MFB). Unlike MNB and MNE, MFE and MFB do not assume that the field measurement is absolutely truth as the error and bias are normalized by the average of the model and observation. It is considered as a more appropriate way to judge the performance of the

model.²⁹ Table 1 summarizes the performance metrics for predictions of wind speeds, wind directions, and BC concentrations. To the best of knowledge, our study is the first one that has introduced MFE and MFB into local-scale air quality modeling.

Wind Speed and Directions—Figures 2a and 2b compare the simulated and measured wind speed and directions, which shows a good agreement. Listed on Table 1, the MFE's and MFB's for the wind speed prediction are 5.40–7.62% and –3.66–6.47%, respectively. For direction prediction, MFE's and MFB's are 2.65–3.17% and 0.67–2.24%, respectively. This suggests that the CTAG model is capable of capturing the flow fields in the highway-building environment. It should be noted that the resolution of the measured wind direction is 22.5°, which results in multiple predicted wind directions corresponding to the same measured values (Figure 2b). The discrepancies between the simulated results and measurements are due to factors such as idealized building and roadway geometries, estimated ambient wind profiles of the lower atmospheric boundary layer and the turbulence model. The capability of capturing the flow fields is critical to our study. Modeled as an inert species, BC's transport is solely governed by turbulence mixing and meteorology. In other words, the absolute values of BC concentrations vary with BC emission factors, but the shapes of horizontal and vertical BC profiles are determined by the flow fields, which are the emphasis of this paper.

BC Concentrations—Figure 2c compares the simulated and measured BC concentrations. The MFE's and MFB's for the CTAG model are –6.46 to 11.77% and –6.46 to –14.08%, respectively. The relative narrow ranges of the two metrics suggest the model performances for the three types of conditions are similar. Boylan and Russell proposed the criteria for acceptable performance for regional-scale air quality modeling as that both the MFE is less than or equal to +75% and the MFB is less than or equal to ±60% for major components of PM_{2.5}.²⁹ In addition, the MNE's (from 16.44 to 21.24%) and MNB's (from –8.20 to –16.44%) in BC concentrations are comparable to those reported by Stein and coworkers in modeling local-scale benzene concentrations (MNE's from 46.37 to 79.87%; MNB's from 9.18 to 34.07%).³⁰ It should be noted that both BC and benzene were modeled as inert species. Therefore, the simulated BC concentrations are in an adequate agreement with the measurements. The further analysis of our modeling results suggests that BC concentrations are systematically underpredicted for a majority (11 out of 14) of the morning rush hours cases shown as solid circles in Figure 2c. A likely contributing factor to the difference between the real-world and modeled data is rooted from our adoption of NYC-regionally average vehicle type distribution in our emission estimates. The traffic videos indicate a large fraction of heavy-duty diesel vehicles in the Category II vehicles during the morning rush hours compared to the assumed average vehicle type distribution. However, the quality of the traffic videos due to the poor viewing angle makes it very difficult to further classify the vehicle size classes. In addition, morning rush hours may lead to transient driving conditions, which can result in higher emissions than cruising conditions. But their effects are expected to be minor because the periods we selected had mostly cruise conditions. As illustrated in the Supporting Information (Section S9), increasing BC emission rates during the morning rush hours significantly improves the modeling performance.

In summary, the CTAG model is adequate to resolve the flow fields and BC concentrations in the highway-building environment under steady-state conditions in spite of the uncertainties in BC emissions. To generalize the results, the BC concentrations in the following sections are normalized by the concentrations on the edge the highway, which to a large extent eliminates the effects of uncertainties in emission estimates.

4.2 Characterizations of the Highway-Building Environment

The evaluated CTAG model provides a valuable numerical tool for characterizing the highway-buildings environment, which we categorize into two main conditions: 1) *highway-building canyon*, and 2) *highway viaduct-building*. *Highway-building canyon* describes the canyon between solid, elevated highway embankment and roadside buildings, where prevailing airflow is forced to flow over the highway (Figure 3a). *Highway viaduct-building*, on the other hand, refers to the space between an elevated highway supported by columns (i.e., a highway viaduct) and roadside buildings, where wind can stream from the space underneath the highway (Figure 3b). Both conditions occur at the U2 site due to the evolving highway geometry of I-87 combined with different wind directions.

Street Canyon—*Highway-building canyon* is analogous to the familiar *street canyon* terminology. There are two aspect ratios associated with a street canyon, H/W and L/H , where H is the average height of building, W is the canyon width, and L is length of the building. Based on H/W and L/H , the characteristics of the flow field and pollutant transport over street canyon can be classified into three categories: isolated roughness flow, wake interference flow, and skimming flow.³¹ Typically, for canyons where $H/W < 0.3$, only the wakes are disturbed (isolated roughness flow). For narrower canyons where $H/W \approx 0.5$, there is a strong interaction between the lee-vortex and windward vortex. Thus, the downward flow of the leeward eddy is reinforced by the windward vortex. In the case of $H/W \approx 1$, where isolated roughness flow transitions to skimming flow (most of the flow does not enter the canyon, and it is similar to simple driven cavity flow where a single vortex is developed).³² In terms of pollutant dispersion, field studies have shown the pollutant concentration is directly linked to the flow field in the canyon, which is described in details in the Supporting Information (Section S7).

Highway-building canyon—The *highway-building canyon* configuration modeled resembles a step-up condition of the street canyon in which the height of urban school U2 is greater than the elevation of the highway embankment.³³ Since H and L are not equal on the upwind and downwind sides, we estimate $H/W \approx 0.65$ by using the average height of highway and U2, and $L/H > 6$ based on the geometry of U2 alone. Thus, the highway-building canyon can be classified somewhere between wake interference flow and skimming flow.³¹ Figure 3a illustrates the vortex circulation due to flow separation inside the *highway-building canyon* between the highway and the urban school (U2) at an ambient wind direction of 225° (Figure 3b will be described in the Highway Viaduct-Building discussion). The flow field is comparable to previous studies on skimming flow over a street canyon.³⁴ Figure 4a depicts the vertical profiles of BC concentration inside the *highway-building canyon* between the highway and the front gate of U2. The height is normalized by the elevation of the highway, and the BC concentration is normalized by the concentration at the edge of the highway. On the leeward wall (2m from the highway), the peak concentration occurs at the level slightly greater than the emission zone. This small rise can be explained by the buoyancy of exhaust produced by the greater temperature on the road surface, and the barrier at the edges of highway. This vertical profile is consistent with the finding in Wang and Zhang.² The vertical BC concentration gradient at the core of vortex circulation (~ 10 m from the edge of the highway) is nearly zero below the highway elevation, indicating a well-mixed region. At the windward wall (the front gate of U2), the maximum concentration occurs at the ground level. The vertical profile of BC concentration can be approximated as a simple exponential function.

Highway Viaduct-Building—Illustrated in Figure 3b, the flow field for the *highway viaduct-building* condition is very different from the *highway-building canyon* condition. There is no primary circulation vortex as shown in Figure 3a. The bulk of the flow from the

bottom of highway is deflected upward once it hits the windward wall of U2, and a small windward eddy is formed (Figure 3b). Figure 4b depicts the normalized vertical BC concentration as a function of distance from the highway. The deflected airflow results in the maximum BC concentration slightly above the top of U2 (“School Front Gate” in Figure 4b). However, the vertical profile of the BC concentration is comparable to *highway-building canyon* near the edge of highway.

Transitional condition—At ambient wind direction around 270° , the highway-building environment is characterized by a transitional condition between the highway-building canyon and highway viaduct-building conditions (Figure 1). Illustrated as “Baseline” in Figure 5, the vertical profile at the front gate of U2 shows that maximum BC concentration occurs around the same height of the highway (~ 8 m), between the ground level, where the maximum concentration occurs in the highway-building canyon condition, and the height of U2, where the maximum concentration occurs in the highway viaduct-building condition. For this transitional condition, the aspect ratio of a highway-building canyon significantly affects pollutant dispersion. We varied the aspect ratios (H/W) to further explore its impact. The first set of simulations vary the height of U2 from 15 m to 25m, 35m, and 45m, corresponding to aspect ratios of 0.58, 0.75, and 0.92 respectively, which redefines the flow regime to skimming flow. Figure 5a shows the vertical profiles of BC concentration at the windward wall (i.e., the front gate of U2). The variation of the flow fields shown in velocity vectors is available in the Supporting Information (Figure S4). As illustrated, BC concentration at the windward wall decreases as height increases, and maximum concentration of all the profiles occurs at the ground level due to circulation vortex. Similar to a step-up canyon, this occurs because the strength of eddies in the canyon grows as windward height increases. Growing eddies increases the dilution and ventilation rate, thus reduces the pollutant concentration.³³ It should be noted that this trend is different from that observed in the case of even street canyons (buildings with similar heights on both sides of the streets), where large aspect ratios (H/W) typically hinder the entrainment of ambient air, resulting in elevated pollutant concentrations.^{35,36}

The second set of simulations increase the distance between the urban school and highway to 40m, 50m, and 60m, effectively reducing H/W from 0.42 to 0.31, 0.25, and 0.21 correspondingly. The flow field evolves toward isolated roughness flow while the interaction of the leeward and windward vortex weakens. At $H/W=0.21$, the flow field resides in the regime where there are co-rotative vortexes, a leeward eddy near highway embankment due to cavity of low pressure, and a smaller windward eddy in front of U2. The maximum normalized BC concentration at the school front gate declines from 0.24 to 0.10 as H/W decreases to 0.21. Further decreasing H/W would result in independent wake flow, which substantially reduces BC concentration. The variation of the flow fields shown in vectors is available in the Supporting Information (Figure S5).

Open highway—In order to estimate how different the BC concentrations are with buildings relative to a situation without airflow obstructions, we conducted simulations of the 34 cases discussed in Section 2 by removing all the roadside structures in our modeling domain while keeping everything else intact, referred to as *open highway* environments. As shown in Figure 4, the vertical BC profiles in the *open highway* environments are distinctly different than those in the highway-building environments (for both *highway-building canyon* and *highway viaduct-building*). It needs to be emphasized that all concentrations presented in Figure 4a and 4b are normalized by the same concentration (i.e., at the edge of the highway). For the 34 cases, the reduction in BC concentrations at the measurement point resulting from building removal varies from 43 to 54%, indicating a significant effect of roadside buildings on near-road air quality.

5. Implication

The CTAG simulations combined with field measurements indicate that flow fields and pollutant transport can vary dramatically in highway-building environments. The CTAG model demonstrates adequate agreement with measurements at U2, and it is able to predict the flow field and spatial gradient of traffic-related air pollutants in complex highway-building environments under steady-state conditions. Under unsteady-state conditions such as those with intermittent wind speed, direction or rapid changing traffics, steady-state profiles may not be achieved. The capability of the CTAG model in capturing the unsteady-state conditions has not been tested yet due to the limitation in the field datasets.

We show that the spatial variation of roadside pollutant concentration in the highway-building environment is dominated by the configuration of the highway, buildings, the relative distances between them, and the prevailing wind conditions. We evaluated two main configurations in a highway-buildings environment: *highway-building canyon* and *highway viaduct-building*, which lead to distinctly different spatial variations of air pollutants, vertically and horizontally. The two configurations may occur at different locations or even in the same location with different wind directions when highway geometry is complex. Furthermore, our simulation results suggest that BC concentration reaches its background level at height about 5 times the height of the highway regardless of types of highway-building conditions.

Our study implies that human exposure to traffic-related air pollutants in a highway-buildings environment, prevalent in urban areas, is governed by both highway and building configurations. Disregarding roadside buildings or highway configurations in a highway-building environment to assess near-road exposure may lead to significant discrepancies. The findings from this study also demonstrate the need for a close collaboration between urban and transportation planners to tackle the near-road air pollution problems in highway-building environments. This kind of collaboration will help towards creating a healthy environment for urban population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.

Sketch of the modeling domain. Encircled are close views of the transition portions of the highway configuration. There are two declining ramps, which are *solid embankments*, at both ends of I-87 in the modeling domain. The middle portion of I-87 is also elevated but with *open space underneath*, referred to as a highway viaduct.

Figure 2.

a) Simulated Vs. Measured Wind Speed b) Simulated Vs. Measured Wind Direction c) Simulated Vs. Measured BC Concentration.

Figure 3. Flow field between highway and urban school (U2) varies with wind direction. *Highway-Building Canyon* conditions (a) occur mostly between solid highway embankment and U2, and *Highway Viaduct-Building* conditions (b) occur mostly between viaduct (middle section of highway shown in Figure 1 with open space underneath) and U2.

Figure 4.

Simulated vertical BC Concentration as a function of distance away from the edge of the highway for a) highway-building canyon and b) highway viaduct-building conditions. Only highway emission source is considered. BC concentration is normalized by the concentration at the edge of highway, and vertical height is normalized by the elevation of the highway modeled. Wind direction is 225° for a) and 292.5° for b).

Figure 5.

Simulated normalized vertical BC profiles at the front gate of the urban school (U2) under the transitional condition with a) Increasing aspect ratio H/W (Increasing the height of U2 from a baseline of 15m to 25m, 35m, and 45m.) and b) Decreasing aspect ratio H/W (Translate U2 further horizontally from a baseline of 30 m away from highway to 40m, 50m, and 60m). All simulations are under the ambient wind direction of 270° . BC concentration is normalized by the concentration at the edge of highway, and the vertical height is normalized by the elevation of the highway modeled.

Table 1

Summary of performance metrics for model evaluation

Statistical Methods	Highway viaduct-building ^a			Highway-building canyon ^b			Transitional condition ^c		
	Wind Speed	Wind Direction	BC	Wind Speed	Wind Direction	BC	Wind Speed	Wind Direction	BC
Mean Normalized Error (MNE)	9.99%	4.12%	21.24%	9.79%	4.30%	16.83%	7.42%	4.90%	16.44%
Mean Normalized Bias (MNB)	8.19%	1.54%	-16.44%	3.09%	3.53%	-8.20%	-4.72%	1.24%	-12.25%
Mean Fraction Error (MFE)	7.62%	2.65%	15.87%	6.80%	2.77%	11.77%	5.40%	3.17%	12.08%
Mean Fraction (MFB)	6.47%	0.90%	-14.08%	2.70%	2.24%	-6.46%	-3.66%	0.67%	-9.38%

^a 15 cases;

^b 13 cases;

^c 6 cases out of total 34 cases.