Urban transport and dispersion model sensitivity to wind direction uncertainty and source location

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HIGHLIGHTS

► We characterize the impact of wind direction uncertainties on dispersion solutions.
► The sensitivity is inversely related to the complexity in the topography.
► There is a broad range of model sensitivities to wind direction uncertainty.

ABSTRACT

The transport and dispersion (T&D) models used for air-quality and defense applications require information describing the source parameters and meteorological conditions to forecast concentration and dosage fields. In many cases the source parameters are known and the meteorological conditions are based on observational data or mesoscale-model-generated forecast conditions. This research examines how errors in the input wind fields translate into uncertainty in the contaminant concentration predictions. In particular, this study focuses on street-level errors in the dispersion patterns that occur in “building aware” T&D models that are sensitive to urban designs (e.g. road and building patterns) and release locations relative to the buildings. This problem was evaluated by first creating a “truth” plume for a given release location and wind direction. Then the T&D model uncertainty associated with input wind errors were determined by comparing plumes calculated using wind directions varied at 2º increments to the truth plume. The uncertainty is quantified as fraction of overlap (FOO). The results are evaluated in a control simulation with no buildings, and in two commonly observed city designs (e.g. a regular grid, and hub and spoke configuration). The analysis examines both idealized building configurations along with the urban topography from cities that represent the regular grid and hub and spoke city designs. Results show that the relative impact of the uncertainty in the meteorological conditions and the corresponding sensitivity of the model to variations in the wind direction vary significantly with the release location and city designs. This suggests that some source locations are less (more) sensitive to uncertainty in meteorological conditions and that this information can be factored into the confidence that is placed in emergency response decisions based on this information.

1. Introduction

Since September 11, 2001, the United States (US) government has made significant investments in sensing and modeling technologies designed to protect the US armed services and homeland against the threats posed by weapons of mass destruction (WMD). These technologies include the development of fast response transport and dispersion (T&D) models that can account for the dispersion of chemical and biological (CB) agents released in urban areas. The need for accurate atmospheric T&D forecasting techniques has become increasingly important because of the threat of an intentional release of hazardous material into the atmosphere, particularly in areas of complex local surface forcing and for longer transport distances (Rife et al., 2004). Although extensive investments have been made to improve the accuracy of these T&D models in urban settings, the accuracy of the solutions are still highly dependent upon the meteorological conditions used. Chang et al. (2003) determined that in cases where meteorological models were coupled with T&D models, the T&D models were strongly influenced by the diagnostic wind model that was used to generate
gridded wind fields from observed winds. Brown et al. (2008) showed that the sensitivities of plume transport in cities to wind direction, including how the street-level flow patterns in cities can be very robust (i.e., unchanging) as the upper-level wind direction changes, and then suddenly shift 180° at critical upper-level wind directions. The research presented here enhances these findings by quantitatively characterizing how errors in the input wind direction translates into street level T&D uncertainty, specifically, into uncertainty in downwind hazard zones.

The urban settings evaluated in this study are designed after two commonly occurring city design characteristics. The first is based on a rectangular grid design and the other is a mix of rectangular grids and a hub-spoke or web-like design. Due to the historic significance, related to its use in the USA and the ready availability of lethal dosage (LD) values, this study uses anthrax and its corresponding lethal exposure concentrations values to define hazard thresholds. Detailed information on the domain characteristics, source placement, and source characteristics can be found in Sections 2.1–2.3 respectively.

This study uses the Röckle (1990) based Quick Urban Industrial Complex (QUIC) Dispersion Modeling System developed at the Los Alamos National Laboratory (LANL) to evaluate the dispersion...
pattern variability associated with wind direction errors. QUIC is a fast-response, urban dispersion modeling system capable of computing three-dimensional wind patterns and dispersion of airborne contaminants around clusters of buildings. The system used is comprised of a wind model (QUIC-URB), a Lagrangian dispersion model (QUIC-PLUME), and a graphical user interface (GUI), QUIC-GUI (LANL, 2007). Hanna and Coauthors (2007) determined that the performance of QUIC-URB/PLUME from LANL was comparable to the performance of other Röckle based models like MicroSWIFT/SPRAY (MSS) from the Science Applications International Corporation (SAIC) & ARIA Technologies, Three-Dimensional Wind Field Model (3DWF) from the Army Research Laboratory (ARL), and the Israel Institute for Biological Research (IIBR) Kaplan and Dinar Model. The QUIC URB/PLUME modeling system is used because its performance was representative of the Computational Fluid Dynamics (CFD) models used when evaluated with the New York City (NYC) Midtown tracer measurements (Allwine et al., 2008) and it is representative of the Röckle class building-aware models and relevant for urban T&D applications like those developed for the Pentagon and surrounding facilities (Warner and Coauthors, 2007).

2. Methods

2.1. Domain characteristics

To evaluate the effect of uncertainty in T&D solutions associated with the input winds; this study uses domains that vary from

![Fig. 4](image1.png) Colonial city, hub spoke design with mixed building heights used in this study and a zoomed view of the downtown area.

![Fig. 5](image2.png) Urban topography from parts of Denver, CO. The area shown was selected so that the domain contained mixed building heights with a grid design.
a simple non-urban domain that serves as a control simulation to the complex urban building configurations. For the complex city designs, this study handles both generalized urban environments and actual building locations and heights from central Denver, CO and Washington, DC. The generalized urban designs diagnose the response of the T&D model to wind direction errors relative to the non-urban control simulation, and are used to infer the models response to a basic category of urban building/road network design. The generalized urban designs are chosen because they are representative of two types of city designs found in North America, a modern city grid design (Fig. 1) and the colonial era, hub and spoke design (Fig. 2). The red outlines in both Figs. 1 and 2 represent individual city blocks where the buildings are 30 m high and cover a spatial footprint of 100 x 100 m. Houston, TX, Portland, OR, and Sacramento, CA are examples of cities with a grid-based building and road structure with city blocks on the order of 100 x 100 m. The generalized urban design illustrated in Fig. 2 was developed to emulate a common characteristic of a hub and spoke urban design where several major streets converge at a city center or square and are narrower in comparison to a modern city street. This design is common in colonial era cities of the northeastern United States like Boston, MA, Philadelphia, PA, and Washington DC. The city blocks in the colonial era design have a spatial footprint of 100 x 100 m and have a building height of 30 m.

The sensitivity of the T&D solution to wind uncertainties in urban environments with mixed building heights is also examined. Many urban centers have a mixture of building heights with tall commercial buildings at the core of the city surrounded by a ring of shorter multi-story buildings and an outer ring of single story buildings. Two generalized urban domains, which incorporate the effects of mixed building heights along with grid vs. hub and spoke urban design, were created for this study. Fig. 3 illustrates the modern city grid design and Fig. 4 illustrates the colonial era urban design with mixed building heights used in this study. The building heights and road networks of the domain in Figs. 3 and 4 respectively were inspired by the buildings from the central business districts of Denver, CO and Boston, MA. The results of the sensitivity

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**Table 1**

Anthrax characteristics from the Lawrence Berkeley National Laboratory database of physical, chemical, and toxicological properties of chemical and biological (CB) warfare agents for modeling airborne dispersion in and around buildings.

<table>
<thead>
<tr>
<th>Biological class</th>
<th>Spore forming</th>
<th>Persistence</th>
<th>Size (µm)</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acinetobacter</em></td>
<td>2 h</td>
<td>Years</td>
<td>~ 1 diameter x ~ 1.5 length</td>
<td>Rod</td>
</tr>
<tr>
<td>Dissemination/route of entry</td>
<td>Incubation/onset</td>
<td>Contagious</td>
<td>50% infective dose (organisms/person)</td>
<td>Untreated lethality (%)</td>
</tr>
<tr>
<td>Spore inhalation, ingestion (rare), broken skin</td>
<td>1–2 h, 1–7 days</td>
<td>No</td>
<td>8000–20,000</td>
<td></td>
</tr>
</tbody>
</table>

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**Table 2**
LC5 values for Anthrax using a probit slope, a spore ratio of 3 x 10^7 spores mg^-1, and a light breathing rate of 0.02 m^3 mg^-1. These values are calculated using the Lawrence Berkeley National Laboratory database of physical, chemical and toxicological properties of chemical and biological (CB) warfare agents for modeling airborne dispersion in and around buildings.

<table>
<thead>
<tr>
<th>LC5 percent</th>
<th>LC5 value (g s m^-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.000078</td>
</tr>
<tr>
<td>10</td>
<td>0.000012</td>
</tr>
</tbody>
</table>

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Fig. 6. Urban topography from parts of Washington, DC. The area shown was selected so that the domain contained mixed building heights with both grid and hub and spoke urban designs.

Fig. 7. Example source locations for the generalized Modern city domain of uniform building heights.
studies using the generalized urban domains described above are contrasted with results from a comparable experiment using the actual urban topography from parts of Denver, CO and Washington, DC. The areas of the cities used were selected so that the domains contain mixed building heights with both grid and hub and spoke urban designs. Figs. 5 and 6 illustrate the buildings used in the T&D sensitivity simulations for these two cities. It is important to note that in these case studies we evaluated one area in each domain to demonstrate how a plume in different urban environments, in a general sense, are affected by errors in the input winds.

2.2. Source placement

The impact of wind uncertainties on an urban T&D solution is also affected by the location of the release location relative to a downwind and upwind building obstruction. To examine this effect, this study uses sources located in three locations: (1) in the middle of the street (or urban canyon), (2) directly upwind of a building obstruction, and (3) upwind of the corner of the building obstruction. Examples illustrating these source locations for the generalized Modern city domain of uniform building heights are shown in Fig. 7.

2.3. Source characteristics

To define a hazard area that could be used in the sensitivity analysis it was necessary to set a threshold that would define the extent of the hazard area from the T&D simulation. Realism was added to the experiment by choosing anthrax as the material being released; its human response characteristics determine the

![Diagram](image-url)
downwind hazard area. The anthrax characteristics (Table 1) and the lethal concentration toxicity (LCT) calculations are derived from the Lawrence Berkeley National Laboratory database of physical, chemical, and toxicological properties of chemical and biological (CB) warfare agents for modeling airborne dispersion in and around buildings (Thatcher et al., 2000).

To quantify anthrax exposure mortality we use different dosage thresholds to identify the hazard areas. These areas are defined within the 50 and 10 LCT (Table 2). The LCT is defined as

\[
\text{LCT} = \frac{\text{LD}}{\text{SR} \times \text{BR}}
\]

where: LD is the lethal dosage (spores), SR is the spore ratio (spores per mass of contaminant released), and BR is the breathing rate (m³ s⁻¹). The thresholds represent the minimum value used to define a hazard zone with an anticipated level of health response within a given population. Any dosage above that value is considered hazardous and any dosage below that value is still hazardous but has a lower probability of lethality relative to this population health response. In this study we deem any dosage below that LCT value to be non-hazardous. Since concentration scales linearly and for simplicity, only results that used an LCT10 threshold (1.2 x 10⁻⁵ g m⁻³) of anthrax are shown.

2.4. Uncertainty calculation procedure

An identical twin setup using the QUIC system is applied to assess the sensitivity of the downwind hazard area from the T&D model to wind direction uncertainties. To assess this sensitivity we first create a “building aware” wind field using QUIC-URB. The prescribed “truth” wind on the upwind side of the release and buildings is set at 3 m s⁻¹ at all levels in the model. QUIC-PLUME is then used to compute the dispersion of 10 kg of anthrax through the urban environment. For the purposes of this identical twin experiment, this plume is now considered as truth against which all of the others are compared. In this way, truth plumes are created for each of the urban configurations and release locations being examined. Next, plumes from the same release location are created with the QUIC system using winds that are varied to emulate wind direction uncertainties. These winds depart from the “true” wind direction value in 2° increments to a maximum of 40° in both the counter-clockwise and clockwise directions from the direction used to produce the truth plumes. The process is repeated for “true” wind directions in each urban design to evaluate the sensitivity in the hazard areas for scenarios where the source is located upwind of building obstructions, urban canyons, and building corners of the building/road network. The plume sensitivity to wind direction at 2 m above ground level at LCT10 are then quantified using the fraction of overlap (FOO), figure of merit in space (FMS), measure of effectiveness (MOE), and normalized absolute difference (NAD) metrics (Warner et al., 2004). The FMS, MOE, and NAD metrics have been tested and evaluated with success against field observations;

Fig. 10. The Fraction Of Overlap (FOO) for the non-urban domain with a function fit that shows a spread of 4.7596.

Fig. 11. Plan view of smoke dispersal through an array of staggered cubes (left) and unobstructed fetch (right). Taken from Brown (2004) but originally published in Davidson et al. (1995).

Fig. 12. Schematic of two plume dispersion patterns expected using small wind direction variations.
however, in this study, given that what we wish to quantify is how well the modeled error plumes line up with respect to the model truth plume, the simple FOO suffices as a metric. The FOO quantifies how well the plume generated from error winds (Error Plume) overlaps with the plume generated from the true wind (Truth Plume). It calculates this by determining the intersection of the Truth Plume and Error Plume and normalizes by the Truth Plume, it is defined as

Fig. 13. Fraction Of Overlap (FOO) statistic and spread value when using a wind direction that transports a plume down an urban canyon in a Modern (○) and the Colonial (●) domain for (a) equal block heights, (b) varying building heights, and (c) the case studies. The Non-Urban domain (dotted line) is also shown for comparison.
FOO = \frac{\text{area}(\text{Truth Plume} \cap \text{Error Plume})}{\text{area}(\text{Truth Plume})}

Thus, we will focus our results in terms of the FOO. Fig. 8 is a schematic of this methodology using the FOO and Fig. 9 shows an example that illustrates this approach using results for the modern grid domain from this study. When using the FOO metric, a higher value of FOO corresponds to a higher tolerance to wind direction uncertainty.

Finally, given that we calculate the FOO at 2° increments to a maximum of 46° in both the counter-clockwise and clockwise directions from the direction used to produce the truth plume, we expect an exponential increase and then decrease in the FOO for a non-urban domain. We created a function that is fit to our non-urban FOO so that we can quantify the spread. This function is defined as

$$\text{Fit} = \frac{A}{(2\pi)^{1/2}} \exp \left( -\frac{\theta^2}{2\sigma^2} \right),$$

where $A/(2\pi)^{1/2}$ is the amplitude, $\theta$ are the wind angle increments, and $\sigma$ is the spread. Then we fit this function to each FOO scenario and optimize the values of the A and $\sigma$ to compare the spread in each scenario to the spread of the non-urban FOO. For the purpose of this analysis the spread corresponds to the relative sensitivity of the hazard zone to uncertainty in wind direction. Larger spread values correspond with lower relative sensitivities to uncertainties in wind direction and smaller spread values correspond with higher relative sensitivities to uncertainties in wind direction. An example of the fit to the non-urban FOO is plotted in Fig. 10.

3. Results and discussion

The goal of this study is to characterize the sensitivity of urban dispersion simulations to uncertainties in the winds used to drive these simulations, and to identify scenarios where urban building and road configurations are more (less) susceptible to these uncertainties. The results provide a means to more accurately characterize simulation uncertainty that is critical to guiding emergency response decisions. The presentation of the results is partitioned to illustrate patterns that correspond with: (3.1) the fidelity/complexity/symmetry of the urban building and road network, (3.2) the impact of the source location relative to the downwind building, and (3.3) how these results depart from the general behaviors discussed in 3.1 and 3.2, when the release location is moved from a major street intersection to a smaller street further from the urban center. Implications of model sensitivity are discussed for each result and are then summarized to provide generalized guidance that can be used by emergency response personnel that rely on these tools.

3.1. Impact of fidelity/complexity/symmetry of the urban topography

Simulation speed is critical for emergency response applications. In many cases simplified urban topographies are used to reduce the number of building elements, thereby reducing the amount of time required to compute a solution. While the reduction of the fidelity of the building data clearly results in a less accurate solution since detailed geospatial information is not available, the impact on the solution sensitivity to wind direction uncertainties is not as clear. Key questions addressed here are: (1) how does the tradeoff between the need for a faster simulation and simulation fidelity influence the dispersion solutions’ sensitivity to errors in the wind fields, and (2) does this vary for building and road configurations in cities with modern vs. colonial layouts. Numerous studies of contaminant dispersion in an urban environment have used uniform grids of building obstructions to characterize the properties of urban dispersion. Fig. 11 is an image of a smoke plume from one such study conducted by Davidson et al. (1995). This figure contrasts smoke plume releases in an urban vs. non-urban domain and illustrates that the plume tends to disperse more in the urban environment of “staggered buildings”. This enhanced dispersion due to the building obstructions also tends to make the staggered scenario more tolerant to wind direction uncertainties because the downwind plume is much wider unlike in the scenario with no “staggered buildings”. These qualitative findings were also documented by Brown et al. (2008). In that study Brown demonstrated that downwind dispersion in urban environments can be highly variable given small errors or uncertainties in the wind direction. This behavior as depicted in Fig. 12, results in situations where small variations (uncertainty in the wind direction) at times result in small variations in the downwind dispersion pattern while other situations with small wind direction uncertainties result in large differences to the downwind dispersion pattern. This property of reduced sensitivity of the dispersed solution to wind direction uncertainties for locations when building obstructions are present is also shown quantitatively in Fig. 13. Here, all of the results for scenarios with buildings indicate a higher FOO score than a corresponding non-urban scenario. This figure also provides an example of how the dispersion solution sensitivity to wind direction uncertainty can vary for different urban topographies. In this example the contaminant release occurs in the center of an urban canyon and the winds are parallel to the street canyon. Fig. 13a shows the FOO results for simulations where simplified urban terrain representing city blocks with a uniform building height are used. The FOO of the contaminant plumes for cities with both uniform grids and grids with large diagonal boulevards (common in the North America colonial era cities) have similar sensitivities, and are a factor of 2.78 and 2.35 respectively, larger than the spread when no buildings are present implying that the size/location of the plume footprint is less sensitive to wind direction. This difference in sensitivity is due to the presence of more narrow “roads” in the colonial domain. When the complexity of the urban topography is increased by adding buildings of differing heights, the dispersion solution becomes slightly less sensitive to the wind uncertainties than the more simplistic urban topography used in Fig. 13a. This point is illustrated in Fig. 13b where FOO results indicate that the simulations for both the modern grid and colonial city designs are a factor of 3.45 and 3.12 respectively, larger than the spread when no buildings are present implying that the size/location of the plume footprint is less sensitive to wind direction. The addition of non-uniform buildings also results in differences in the error

<table>
<thead>
<tr>
<th>Spread</th>
<th>Source location</th>
<th>Urban canyon</th>
<th>Building corner</th>
<th>Building obstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Similar building height</td>
<td>Varying building height</td>
<td>Building obstruction</td>
</tr>
<tr>
<td>Constant building height</td>
<td>Modern</td>
<td>2.78</td>
<td>2.09</td>
<td>2.21</td>
</tr>
<tr>
<td>Varying building height</td>
<td>Modern</td>
<td>2.35</td>
<td>2.48</td>
<td>2.04</td>
</tr>
<tr>
<td>Case studies</td>
<td>Denver</td>
<td>3.12</td>
<td>3.18</td>
<td>3.95</td>
</tr>
<tr>
<td>DC</td>
<td>6.61</td>
<td>3.41</td>
<td>–</td>
<td>3.54</td>
</tr>
</tbody>
</table>
sensitivity between the positive and negative wind direction differences. Fig. 13b which shows the modern grid indicates more tolerance to wind direction uncertainty because the larger buildings in the downtown area appear to channel the plume more efficiently than in a colonial grid smaller buildings and narrower streets. This Fig. 13c shows the results for the comparable FOO analysis for the urban topographies of the cities of Denver, CO and Washington, DC where the urban canyon formed in each scenario are between buildings of similar heights. In this example the urban topography is substantially more complex than was used in the
simulations shown in Fig. 13a and b. Of the two “real-world” cities examined, Washington, DC has smaller but more buildings. The portion of Denver used in the analysis has larger and taller buildings. The inverse relationship between complexity of the urban topography and the sensitivity of the atmospheric dispersion solution to wind direction uncertainties is also evident in Fig. 13c (Table 3 under Urban Canyon, Similar Building Height). The FOO values for both Denver and Washington, DC are larger than those seen in Fig. 13b with Washington DC environment having the most complex urban topography and was a factor of 6.61 larger than the spread when no buildings are present implying that the size/location of the plume footprint is less sensitive to wind direction. A full list of all of the normalized spread values for each of the building scenarios can be found in Table 3.

Fig. 14a–c depict results for a comparable experiment to that shown in Fig. 13 except that in this case the base wind direction and release location are confined so that a building obstructs the contaminant dispersion directly downwind of the release. In this case an inverse relationship between complexity of the urban topography and the sensitivity of the atmospheric dispersion solution to wind direction uncertainties is again evident. While the results between the modern and colonial era cities tend to be similar to each other for the less complex specifications of the buildings/roads, the FOO results shown in Fig. 14c show a reversal of the results from 13c for errors less than 15° from the true wind. For errors larger than 15° from the true wind we see that Denver is less tolerant to errors because the plume does not interact with and is not channeled by as many buildings as for Washington D.C. This finding suggests that while the results presented here represent the general behavior of the model, there can be specific instances of building configurations where this behavior does not apply.

This inverse relationship between the complexity of the urban topography and solution sensitivity to wind uncertainties can be more clearly seen in Fig. 15, which shows the spread of the FOO results plot for the scenarios of increasing complexity in the building/street configurations. The abscissa in this plot ranges from low complexity of configuration, non-urban on the left to the larger complexity configuration, Washington DC results on the right. This figure also includes the results from Figs. 13a/14a, 13b/14b, and the Denver and Washington DC FOO results from both sets of simulations. The results imply that cities with complex building topographies typically see a broader pattern of dispersion, and consequently, changes to the input winds have less of an impact on the solution. There is only a slight difference between the results when there was and was not a building obstruction downwind of the release location.

In summary, these results for our specific release location indicate that the urban dispersion model solutions for North American colonial era cities (common on the US East Coast) are less sensitive to wind direction uncertainties than the cities built more recently that typically follow a relatively uniform grid. This finding is due to the greater complexity in the urban building/road network. However, in order to fully capitalize on this behavior of the urban dispersion model, it is necessary to have sufficient fidelity in the urban building/road data sets used in the models.

3.2. Impact of the source location relative to the downwind building

The location of a contaminant source coupled with the wind direction and complexity of the urban environment results in a large number of possible release scenarios. This portion of the study attempts to consolidate these scenarios into three basic categories. The first is the situation where the release occurs in the street canyon and the nominal wind direction is such that the contaminant is carried downwind without any short-range building obstructions. The second is a situation where the release again occurs in the street canyon, but this time the nominal wind direction is such that the contaminant is carried downwind directly into the face of a nearby building. The third category of scenario examined is the situation where the contaminant release occurs in an intersection of streets and the nominal wind direction is such that the contaminant is carried downwind into the corner of the building. The question being addressed here is, does the wind direction and release location relative to down-wind building obstacles influence the solutions sensitivity to errors in the prevailing wind direction?

Figs. 16 and 17 provide a comparison of FOO results that address this question and illustrate the impact of source location relative to downwind buildings for both the idealized modern and colonial city designs. The urban topography used in the analysis displayed in Fig. 16 is the more simplistic representation of the buildings where the building obstacles represent entire city blocks. The urban topography in Fig. 17 represents a more complex representation of the buildings where individual buildings of varying height are prescribed. The FOO analysis results in both cases suggest that situations where the corner of the building obstructing is directly downwind of the release is the least sensitive to wind direction uncertainties. In Figs. 16 and 17, the results are mixed for the situations where the release is carried downwind through the urban canyon and the face of a building is directly downwind from the release. In each of these scenarios the model solutions are more sensitive to the wind direction uncertainties than the building corner case but roughly comparable to each other and similar between modern and colonial city designs. In Fig. 16b, both the Modern and Colonial domains have symmetric FOOS and in Fig. 16c, they both become less symmetric. The release location being in a “main” avenue for the Colonial domain, better channeled for the corner release (Fig. 16c) as well as, the release location being in a larger center plaza area. Fig. 18 summarizes this finding by plotting the spread of the FOO results for the scenarios illustrated in Figs. 16 and 17 where the release locations are varied relative to the downwind building obstructions. The abscissa in this plot ranges on the left from the scenario where there is not a building directly downwind of the release in the truth simulation, to a scenario where a building is directly downwind of the release, to a scenarios where the release occurs directly upwind of the corner of a building on the right.

Fig. 15. Function spread for modern, colonial, and case studies for urban canyon and building obstruction scenarios.
3.3. Results that depart from the generalized wind-error sensitivity behaviors

Due to the complexity of many urban landscapes it is difficult to break a release scenario down to a single category. In reality, the real-world urban landscapes combined with the release scenario is likely to be a combination of several categories and their corresponding effect on the sensitivity of the solution to wind direction errors. An example of this response can be seen in Fig. 19. This figure shows the FOO analysis results for scenarios where the

![Canyon](image1)

![Obstruction](image2)

![Corner](image3)

*Fig. 16. Fraction Of Overlap (FOO) statistic and spread value when using a wind direction that advects a plume towards an urban canyon (a.), building obstruction (b.), and a building corner (c.) in a Modern (○) and the Colonial (●) domain with equal block heights. The Non-Urban domain (dotted line) is also shown for comparison.*
contaminant flows toward a nearby building corner. Here the FOO results for the colonial city layout are skewed higher to the left of 0° and the modern city layout FOO results are skewed much higher to the right of 0°. This illustrates the channeling effects that large buildings near the source location can have on the dispersion patterns and corresponding sensitivities to wind direction uncertainties. A similar example can be seen in Fig. 20, which illustrates the FOO analysis solutions for scenarios where the contaminant flows down urban canyons in Denver and Washington, DC without any direct obstruction from a nearby building, but here the canyon includes significantly varying building heights (Table 3 under Urban Canyon, Varying Building Heights). In Fig. 20a
we see that the modern city layout is more sensitive to wind direction uncertainties than the colonial city layout, while 20b shows the opposite result when a different baseline wind direction that carries the contaminant down alternative urban canyon is selected. In this situation there is little difference in the Denver results when the baseline wind direction is changed, but a larger change in the Washington DC results. This is largely due to size of the urban canyon. The baseline wind direction carries the contaminant from Dupont Circle down Massachusetts Avenue in Fig. 13a, which is a much wider urban canyon than the results shown in Fig. 20b where the baseline winds carry the contaminant from Dupont Circle down the narrower 19th Street.

4. Conclusions

Modeling contaminant dispersion in urban environments is a critical capability for the emergency response community. This community relies on the accuracy of the results from these tools to make decisions that impact the health and safety of both the general public and first responders during both intentional and accidental airborne releases of hazardous materials. In spite of the fact that during these crisis situations, high quality weather information is sometimes not available, critical decisions still need to be
made. In these situations, emergency response managers need to have a measure of confidence in the dispersion model results. This work addresses this need by characterizing the impact of wind direction uncertainties on the corresponding dispersion solutions. The results of this study indicate that there are some general rules of thumb that can be applied to the problem of how sensitive the dispersion solution is to wind direction errors. First, the sensitivity of dispersion solutions to uncertainties in wind direction is inversely related to the complexity and dynamic variability in the urban topography. In cases where the complexity of the urban topography is artificially reduced by simplifying the building database to improve the speed of the solution, the resulting solution becomes more sensitive to wind direction uncertainty. Second, simulation results from releases that occur directly upwind of a corner of a building are less sensitive to wind direction uncertainties than those scenarios where there is no obstruction directly downwind or the face of a building is directly downwind. Third, the presence of large buildings near the release location can act as large barriers to the flow and corresponding material dispersion and strongly influence the sensitivity of the solutions to wind direction. Fourth, the presence or lack of major (wide) streets, which act as large urban canyons, can result in significant differences in the sensitivity of the model solutions to the wind uncertainty. Finally, this analysis indicates that there is a broad range of model sensitivities to wind direction uncertainty. While this may make it challenging to identify generalized solutions to the wind direction uncertainty problem affecting the emergency response community, it does mean that there are release scenarios and locations that are very tolerant to wind direction uncertainties. This finding suggests that for important locations it may be beneficial to pre-compute the wind direction error sensitivities so that they will be readily available should the need unfortunately arise.

References


