Transport & Dispersion Model Sensitivity to Input Winds and Source Location

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SOARS® Summer 2007

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ABSTRACT
Many transport and dispersion (T&D) models use observational data or mesoscale-model-generated forecast winds as input. This research examines how errors in these input wind fields can translate into T&D model solution errors. In particular, this study focuses on street-level plume errors that occur in building aware T&D models for a set of scenarios where the release location varies relative to the building locations. This problem was evaluated by first creating a “truth” plume for a given release location and wind direction. Then the T&D model errors associated with input wind errors were determined by comparing plumes calculated using wind directions varied at 2° increments to the truth plume. Results show that the relative impact of input errors vary significantly with the release location and the wind direction relative to buildings.

The Significant Opportunities in Atmospheric Research and Science (SOARS) Program is managed by the University Corporation for Atmospheric Research (UCAR) with support from participating universities. SOARS is funded by the National Science Foundation, the National Oceanic and Atmospheric Administration (NOAA) Climate Program Office, the NOAA Oceans and Human Health Initiative, the Center for Multi-Scale Modeling of Atmospheric Processes at Colorado State University, and the Cooperative Institute for Research in Environmental Sciences. SOARS also receives funding from the National Center for Atmospheric Research (NCAR). SOARS is a partner project with Research Experience in Solid Earth Science for Student (RESESS).
1. Introduction:

Since the events of September 11, the government has deemed necessary the enhancement of defense technology and has invested financially in preventive science to protect the United States of America. Due to the threat of terrorism, these preventive measures include developing fast transport and dispersion (T&D) models that can account for biological and chemical agents as contaminant sources in urban areas. In 2004, Rife stated that the need for accurate T&D forecasting techniques had 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. Although there has been extensive research to make these T&D models more accurate within the context of an urban building-aware setting, mesoscale-model-generated forecast winds must still be employed as input in T&D models. In 2003, Chang determined that in cases where meteorological models were coupled with T&D models that the T&D models were strongly influenced by the diagnostic wind model that was used to generate gridded wind fields from observed winds. This research characterizes how errors in the mesoscale-model-input winds translate into T&D errors, specifically, into street-level building-aware plume errors. These errors are quantified for different urban settings and source release locations.

To evaluate these wind errors, the Röckle (1990) based model developed at the Los Alamos National Laboratory (LANL), known as Quick Urban Industrial Complex (QUIC) Dispersion Modeling System, is used. QUIC is a fast-response urban dispersion modeling system that computes three-dimensional wind patterns and dispersion of airborne contaminants around clusters of buildings. The system is comprised of a wind model, QUIC-URB, and a Lagrangian dispersion model, QUIC-PLUME, and a graphical interface, QUIC-GUI (LANL 2007).

2. Methods:

For this project the QUIC system was used to calculate a plume with a base wind speed and direction of 1 m/s and 270° on the upwind side of a non-urban domain (Figure 1). Afterward plumes from the same release location were computed using error winds that depart from the arbitrary wind direction value by, 2° increments for 40° counter-clockwise and clockwise of the base wind. The plume sensitivity to wind direction error was determined by the overlapping area. Subsequently, the base wind was changed by 25° degrees from 220° through 320° and then once again error winds were computed and their overlapping areas quantified. This was also done for three different source release locations (Figure 2) on a symmetric rectangular urban domain with equal sized average buildings blocks addressing the question of whether the urban T&D problem was more sensitive to large-scale wind error than it is to a non-urban problem. Finally, a third scenario used a more complex urban domain building data set from a city, in this case Oklahoma City (OKC), was used because many urban areas share similar characteristics. For OKC the base wind was varied from 0 through 345 degrees at 15° increments and error winds were computed at 3° increments for 45° counter-clockwise and clockwise of the base wind.
Figure 1. Non-urban domain showing two different plumes with overlapping area as well as base winds of 220° (blue), 245° (pink), 270° (yellow), 295° (turquoise), and 320° (purple).

Figure 2. Symmetric 3000 x 3000 x 80 m$^3$ domain with 300 x 300 x 30 m$^3$ averaged sized building blocks with the three different source release locations: urban canyon, building front, and building corner.

3. Results and Discussion:

a. Non-Urban Setting

In a non-urban setting (figure 3) for base winds that vary from 220° through 320° at 25° increments, the larger the wind angle difference the less percent of overlapping area. This is what is expected.
Averaged Percent Areas Overlap: Non-Urban Domain

Figure 3. Plot for a non-urban domain of the percent of overlapping plume area for base winds of 220° (blue), 245° (pink), 270° (green), 295° (orange), and 320° (purple), with wind errors averaged by magnitude of the wind difference in the 40° threshold.

b. Symmetric Urban Setting

1.) Urban Canyon

In a symmetric urban setting with a release location upwind of the center channel of an urban canyon the base wind was varied from 220° through 320° at 25° increments. Figure 4 shows an eventual percent of overlapping area decrease as the wind angle difference increases. For this setting the decrease was not as steep as the non-urban setting. An interesting feature in this plot is that if the wind is directly upwind the urban canyon, as the 270° base wind, a larger wind angle difference is permitted without compromising the percent of overlapping area until there is more than a 24° wind angle difference.
Figure 4. Plot for an urban domain and center channel release source location of the percent of overlapping plume area for base winds of 220° (blue), 245° (pink), 270° (green), 295° (orange), and 320° (purple), with wind errors averaged by magnitude of the wind difference in the 40° threshold.

2.) BUILDING FRONT

In a symmetric urban setting with a building front release location the base wind was varied from 220° through 320° at 25° increments. Figure 5 shows an eventual percent of overlapping area decrease as the wind angle difference increases.
Averaged Percent Areas Overlap: Building Front

Figure 5. Plot for an urban domain and building front release source location of the percent of overlapping plume area for base winds of 220° (blue), 245° (pink), 270° (green), 295° (orange), and 320° (purple), with wind errors averaged by magnitude of the wind difference in the 40° threshold.

3.) Building Corner

In a symmetric urban setting with a building corner release location the base wind was varied from 220° through 320° at 25° increments. Figure 6 shows an eventual percent of overlapping area decrease as the wind angle difference increases. The curve in this plot has characteristics of the center channel release and building front curves.
Figure 6. Plot for an urban domain and building corner release source location of the percent of overlapping plume area for base winds of 220° (blue), 245° (pink), 270° (green), 295° (orange), and 320° (purple), with wind errors averaged by magnitude of the wind difference in the 40° threshold.

c. Non-Urban vs. Urban Setting

Figure 7 shows the average of the base wind curves of each source release location for a symmetric urban domain and the average of the base wind curves for a non-urban domain. This plot can be divided into two areas, the first being above 60% of overlap and the other below 60% of overlap. Above this cutoff the urban setting curves are steeper than the non-urban domain. Below the cutoff the non-urban domain curve is steeper than the urban domain curves, implying that the buildings actually help maintain larger percent area overlaps when wind errors increase. This less steep decrease after 60% overlap can be due to the buildings decreasing the wind speed and dispersing the plume less therefore the curve of area overlap levels out at a higher percent level.
Non-Urban vs. Urban Domains

Figure 7. Plot of the averaged baselines for the non-urban domain (blue) and the three different source release locations of the symmetric urban domain (center channel, pink; building front, green; building corner, orange) with wind errors averaged by magnitude of the wind difference in the 40° threshold.

d. Oklahoma City

For the case study of Oklahoma City the source release location is shown in figure 8. Figures 9-12 show base wind plumes from 0° through 345° varying every 15° and the overlapping areas with plumes from error winds every 3° for 45° counter-clockwise and clockwise. With more buildings the decrease in overlapping area is less steep.
Figure 8. Oklahoma City with source release location shown in red.

Averaged Percent Areas Overlap: OKC 0-90

Figure 9. Plot of OKC and release source location shown in figure 8, of the percent of overlapping plume area for base winds of 0° (blue), 15° (pink), 30° (green), 45° (orange), 60° (purple), 75° (maroon), and 90° (grey) with wind errors averaged by magnitude of the wind difference in the 45° threshold.

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Figure 10. Plot of OKC and release source location shown in figure 8, of the percent of overlapping plume area for base winds of 105° (blue), 120° (pink), 135° (green), 150° (orange), 165° (purple), and 180° (maroon) with wind errors averaged by magnitude of the wind difference in the 45° threshold.
Averaged Percent Areas Overlap: OKC 195-270

Figure 11. Plot of OKC and release source location shown in figure 8, of the percent of overlapping plume area for base winds of 195° (blue), 210° (pink), 225° (green), 240° (orange), 255° (purple), and 270° (maroon) with wind errors averaged by magnitude of the wind difference in the 45° threshold.
Averaged Percent Areas Overlap : OKC 285-345

Figure 12. Plot of OKC and release source location shown in figure 8, of the percent of overlapping plume area for base winds of 285° (blue), 300° (pink), 315° (green), 330° (orange), and 345° (purple) with wind errors averaged by magnitude of the wind difference in the 45° threshold.

4. Conclusion:

After analyzing the previous results a clearer picture of a problem developed. The results show that the impact of input errors vary significantly with the release location and the wind direction with respect to the buildings. To actually determine a cutoff value for how much wind error is acceptable without significantly affecting the plume and contaminant area, more research is needed. This includes evaluating the dosages of contaminant over all time and all levels for each of the scenarios previously shown, as well as determining thresholds of lethal contaminant.
REFERENCES


