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# TESTING OF AN URBAN LAGRANGIAN DISPERSION MODEL USING GAUSSIAN AND NON-GAUSSIAN SOLUTIONS

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## 1. INTRODUCTION

The QUIC-Plume (Quick Urban & Industrial Complex) fast response transport and dispersion code (Williams and Brown, 2002) uses the Langevin equations (Rodean, 1996) to model the turbulent dispersion of a passive scalar and estimate concentrations in discrete volumes. QUIC-Plume has been designed to be used with QUIC-URB (Pardyjak and Brown, 2001), a 3D fast response model that computes a mass consistent wind field around buildings using empirical parameterizations.

In the work presented here, baseline calculations have been run to ensure QUIC-Plume's performance under idealized conditions. QUIC-Plume was compared to a Gaussian model (uniform velocity profile, elevated release, see Fig. 1) and a non-Gaussian model (power-law velocity profile, elevated release, see Fig. 2). In addition, a nested grid capability was implemented into QUIC-Plume in order to speed up the model and still obtain good results.

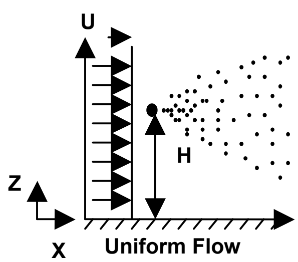


*Figure 1:Schematic of the uniform flow release case.*

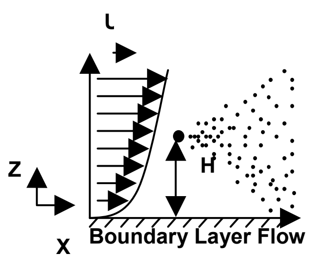


*Figure 2: Schematic of the power law boundary layer flow release case.*

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## 2. METHODOLOGY

### 2.1 Gaussian Plume model for uniform velocity profile flow

Under certain idealized conditions (steady state, horizontal homogeneity, constant wind speed, and constant eddy diffusivity), the conservation equation for a passive scalar emitted from a point source yields a Gaussian solution (e.g., Seinfeld and Pandis, 1998). The vertical and crosswind dispersion parameters for neutral conditions were estimated according to Draxler's (1976) simplification of Pasquill's (1971) suggested definition, where dispersion in the crosswind and vertical directions is directly proportional to the product of standard deviation of the respective wind velocities, elapsed time and a universal function dependent upon atmospheric boundary layer parameters (Draxler, 1976). The friction velocity, u*, needed in the QUIC-Plume model was estimated by comparing the Draxler horizontal and vertical dispersion parameters with the standard Pasquill and Gifford dispersion parameters for neutral atmospheric conditions (e.g., Seinfeld and Pandis, 1998).

### 2.2 Non-Gaussian Plume model for power-law velocity profile flow

Berlyand (1975) and Huang (1979) have shown that the passive scalar conservation equation can be solved for power-law velocity and vertical eddy diffusivity profiles. The non-Gaussian solution has been shown to match concentrations distribution well in boundary layer shear flow (Brown *et al.*, 1993). The crosswind spread parameters for the non-Gaussian model were evaluated according to Pasquill (1971). The friction velocity was calculated within the QUIC-Plume model using the gradient of the boundary layer power-law velocity profile.

### 2.3 QUIC-Plume set up

Within the QUIC-Plume code, a passive scalar was released continuously from an elevated point source located in the domain. For the uniform flow test case, a domain of size 100 m in the streamwise direction, 100 m in the crosswind direction and 140 m in the vertical direction was used with a release height of 70m. The plume was released at a height such that the plume would not impact the ground within the computational domain. This was done to avoid near-ground reflections. For the power-law velocity profile case, a domain of size 100 m in the streamwise direction, 100 m in the crosswind direction and 20 m in the vertical direction was used with a release height of 11m.

For the shear flow case, QUIC-Plume was run with a power law velocity profile with an exponent of 0.15. The friction velocity was computed internally based on the gradient of the velocity profile. For the uniform flow test case, QUIC-Plume requires specification of the friction velocity, i.e., it cannot be specified from velocity gradients. As mentioned above, u* was calculated by equating the Draxler plume spread equation to the Pasquill-Gifford equation and solving for the friction velocity.

In QUIC-Plume, the concentrations are computed by counting particles in a 3D array of sampling boxes. Grid refinement tests showed that in order to sufficiently match near source results, fine grid resolutions were necessary. To efficiently capture both the near-source and far-field concentration variations, the QUIC-Plume code was modified to incorporate embedded grids near the source to allow for localized high-resolution calculations.

The QUIC-Plume simulations were performed with an outer grid resolution of approximately 10 m X 10m X 10m in streamwise, crosswind and vertical directions, respectively, and a fine embedded grid near the source of approximately 10/7m X 10m X 10m in streamwise, crosswind and vertical directions, respectively. 50,000 particles were released for these simulations. The concentration calculations were then made for the specified sampling boxes and a concentration value was assigned to the center location of the given box.

## 3. RESULTS

### 3.1 QUIC-Plume Evaluation using the Gaussian Model (uniform velocity profile)

To compare the Gaussian and QUIC-Plume model runs, the concentration was normalized as follows:

$$C^* = \frac{CU_h h^2}{Q}$$

where

$C^*$ = Normalized concentration

$C$ = Concentration (gm$^{-3}$)

$h$ = Height of point of release (m)

$U_h$ = Velocity at the of point of release (ms$^{-1}$).

$Q$ = Source strength (gs$^{-1}$)

Figure 3 shows the near centerline (4m offset) concentration variation in the streamwise direction. QUIC-Plume (QP) predicts the concentration along the centerline fairly well. It is clear that the improved resolution from the embedded grid gives a much better estimate of concentrations near the source. Close to the source, the coarse grid misses both the amplitude of the peak and the location.

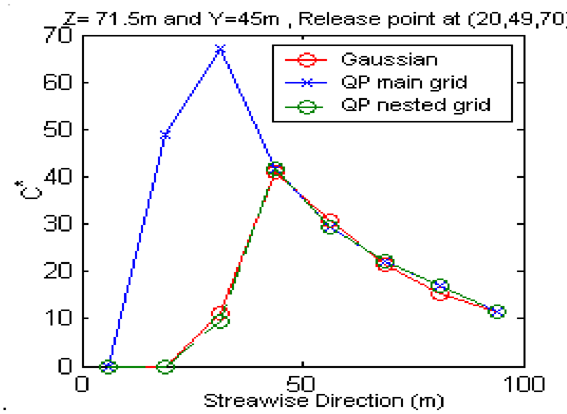


*Figure 3: Near centerline plot of concentration vs. streamwise direction for an elevated release in a uniform flow.*

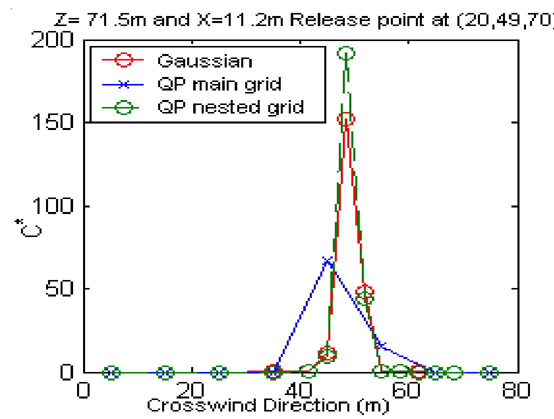


*Figure 4: Near source plot of concentration vs. crosswind direction for an elevated release in a uniform flow.*

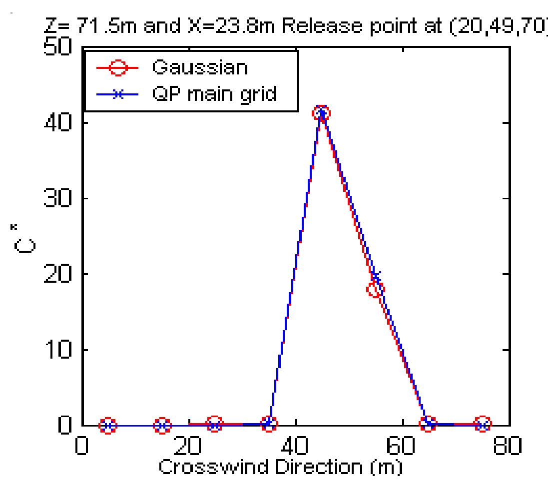


*Figure 5: Far source plot of concentration vs. crosswind direction for an elevated release in a uniform flow.*

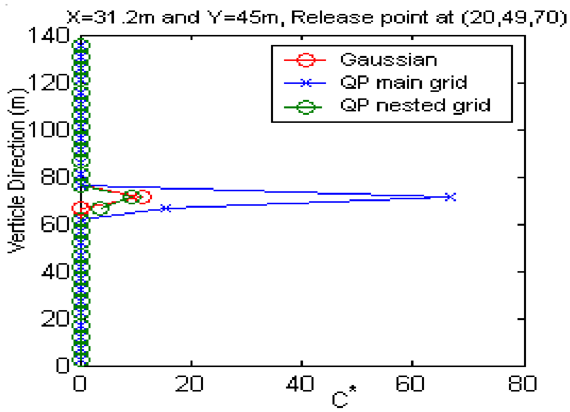


*Figure 6: Near source plot of vertical direction vs. concentration for an elevated release in a uniform flow.*

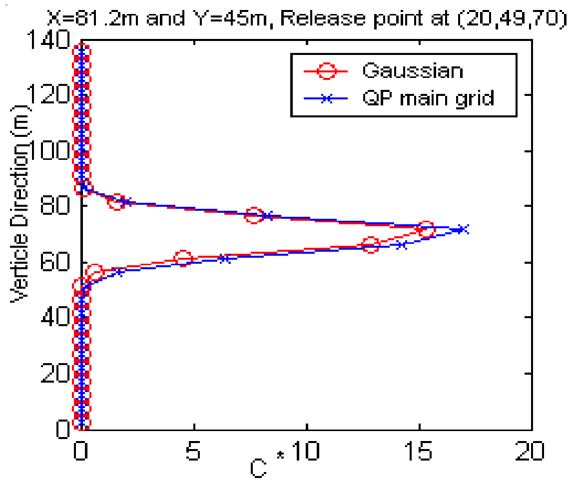


*Figure 7: Far source plot of vertical direction vs. concentration for an elevated release in a uniform flow.*

Figures 4 and 6 show the QUIC-Plume model matches the Gaussian solution well in the lateral and vertical directions too when using the high resolution grid. The blue curves show that the spatial resolution of the coarse grid is not adequate near the source. As can be seen from Figs. 5 and 7, QUIC-Plume also predicts the lateral and vertical profiles well as we move farther away from the source.

**3.2 QUIC-Plume Evaluation using the Non-Gaussian Model (power-law velocity profile):**

Figure 8 compares the near centerline (approx 3m offset) concentration computed by the non-Gaussian model and QUIC-Plume as a function of downwind distance. As was the case for the uniform flow, QUIC-Plume predicts the location and magnitude of the peak fairly well using the high resolution grid. Near the source, the coarse grid over estimates the concentration.

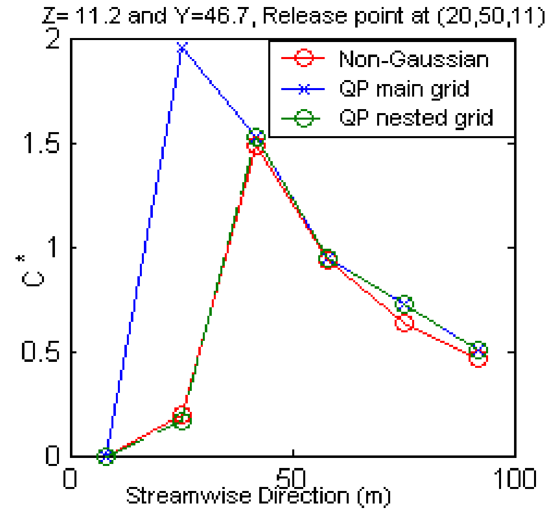


*Figure 8: Near centerline plot of concentration vs. streamwise distance for a power law velocity profile.*

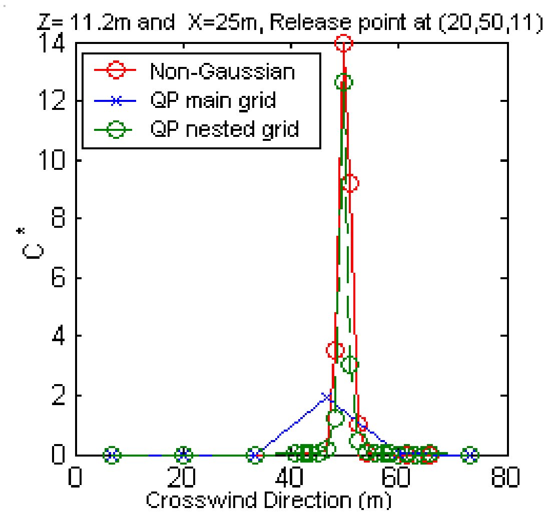


*Figure 9: Near source plot of concentration vs. crosswind distance for a power law velocity profile.*

The QUIC-Plume model also accurately predicts the lateral and vertical concentration profiles near the source as seen in Figs. 9 and 11, respectively. It is also clear that close to the source, fine resolution is needed to obtain accurate answers. As can be seen from Figs. 10 and 12, QUIC-Plume also predicts the lateral and vertical profiles well as we move further away from the source.

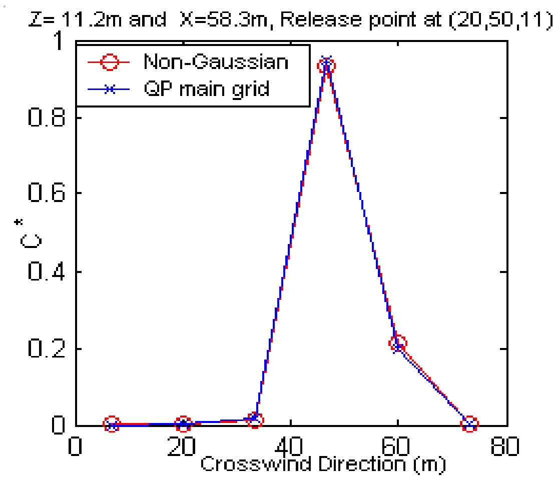


*Figure 10: Far source plot of concentration vs. crosswind distance for a power law velocity profile.*

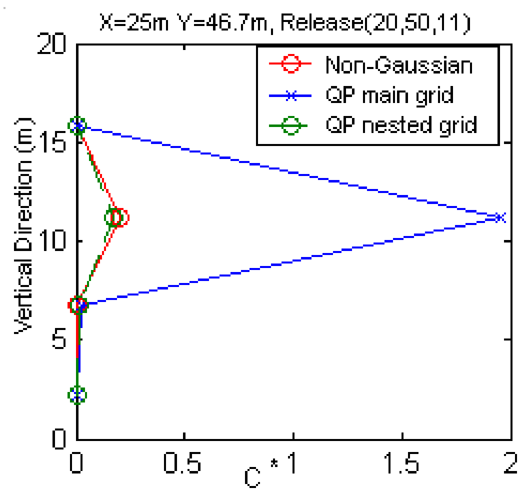


*Figure 11: Near source plot of vertical direction vs. concentration for a power law velocity profile.*

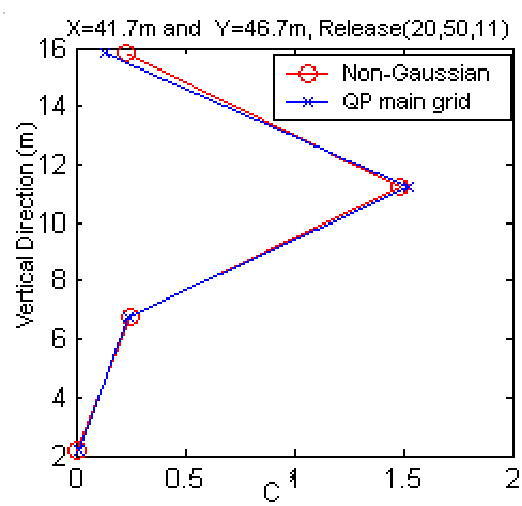


*Figure 12: Far source plot of vertical direction vs. concentration for a power law velocity profile.*

## 4. SUMMARY

The purpose of this work was to evaluate the QUIC-Plume Lagrangian dispersion model under very idealized conditions. This was accomplished by comparing QUIC-Plume results with the Gaussian and Non-Gaussian plume models using uniform and power-law wind profiles, respectively. Comparisons of longitudinal, lateral, and vertical profiles of concentration show that the QUIC-Plume model matches both the Gaussian and non-Gaussian model results well. In order to speed up calculations, a nested concentration grid capability was incorporated into QUIC-Plume. This fine grid allows for better concentration estimates near the source, while the coarse grid gives acceptable concentration estimates far from the source. In future, we will look at near-surface releases in order to better evaluate the reflection scheme in the code.

## 5. REFERENCES


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