J1.12 DEVELOPMENT OF A DISPERSION MODEL FOR FLOW AROUND BUILDINGS

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1. Introduction

Complex flows develop around buildings and pose difficult challenges to dispersion modelers. This paper describes the development of a new fast response model, QWIC-PLUME, that can be used to describe dispersion near buildings. The model is designed to be used with the QWIC-URB model (Pardyjak and Brown, 2001) that computes a mass consistent wind field for flows around buildings. QWIC-PLUME is a Lagrangian transport code based on the Langevin equations. For urban applications, the assumption of horizontal homogeneity cannot be made, hence the model equations are slightly different than those found in traditional random-walk codes.

2. Model Description

Lagrangian particle models describe dispersion by simulating massless particles moving with an instantaneous wind composed of a mean wind plus a turbulent wind. The equation that describes the x coordinate of the particle positions is:

$$x(t+dt) = x(t) + Udt + \frac{u'(t+dt) + u'(t)}{2}dt,$$

where U is the mean wind, u' is the fluctuating component of the instantaneous wind and dt is the time step. Mean winds are winds averaged over a sufficient length of time (usually 10 minutes to an hour) to remove the effects of random fluctuations.

The fluctuating component of the instantaneous wind is calculated from:

$$u'(t+dt) = u'(t) + du.$$

Similar expressions apply to the y and z position coordinates and the v and w components of the wind.

Generally, the equations for *du, dv,* and *dw* are quite complicated, but dramatic simplifications can be made if the mean vertical wind *W* is zero, the mean horizontal winds are uniform and the coordinate system is rotated so that the mean wind is in the x-direction (*V=W=0)*. Under these circumstances (Rodean, 1996, pages 43-44), the expressions for *du, dv,* and *dw* are:

$$du = \left\{\frac{-Co\varepsilon}{2}\left[\lambda_{11}u' + \lambda_{13}w\right] + \frac{\partial U}{\partial z}w + \frac{1}{2}\frac{\partial \tau_{13}}{\partial z}\right\}dt +$$
$$\left\{\frac{\partial \tau_{11}}{\partial z}\left[\lambda_{11}u' + \lambda_{13}w\right] + \frac{\partial \tau_{13}}{\partial z}\left[\lambda_{13}u' + \lambda_{33}w\right]\right\}\frac{w}{2}dt +$$
$$\left(Co\varepsilon\right)^{1/2}dW_1,$$

$$dv = \left[-\frac{Co\varepsilon}{2}\left(\lambda_{22}v\right) + \frac{\partial \tau_{22}}{\partial z}\left(\lambda_{22}v\right)\frac{w}{2}\right]dt + \left(Co\varepsilon\right)^{1/2}dW_2,$$

and,

$$dw = \left\{-\frac{Co\varepsilon}{2}\left[\lambda_{13}u' + \lambda_{33}w\right] + \frac{1}{2}\frac{\partial \tau_{33}}{\partial z}\right\}dt +$$
$$\left\{\frac{\partial \tau_{13}}{\partial z}\left[\lambda_{11}u' + \lambda_{13}w\right] + \frac{\partial \tau_{33}}{\partial z}\left[\lambda_{13}u' + \lambda_{33}w\right]\right\}\frac{w}{2}dt +$$
$$\left(Co\varepsilon\right)^{1/2}dW_3,$$

with,

$$\lambda_{11} = \left(\tau_{11} - \tau_{13}^2/\tau_{33}\right), \qquad \lambda_{22} = \tau_{22}^{-1},$$

$$\lambda_{13} = \left(\tau_{13} - \tau_{11}\,\tau_{33}/\tau_{13}\right)^{-1}, \ \lambda_{33} = \left(\tau_{33} - \tau_{13}^2/\tau_{11}\right)^{-1},$$

$$\tau_{11} = \sigma_u^2, \quad \tau_{22} = \sigma_v^2, \quad \tau_{33} = \sigma_w^2.$$

Co is the universal constant for the Lagrangian structure function. A variety of investigators have estimated a plethora of values ranging from 1.6 to 10 and we have chosen a value of 5.7 (Rodean, 1996, page 8). ε is the mean rate of turbulence kinetic energy dissipation. dW_1, dW_2, and dW_3 represent random number generators that are normally distributed functions with means of zero and standard deviations of 1 and are uncorrelated in time. In the surface stress layer, we have the following parameterizations:

$$u_* = k\Delta z\frac{\partial U}{\partial z},$$
$$\sigma_u = 2u_*, \quad \sigma_v = 2u_*, \quad \sigma_W = 1.3u_*,$$
$$\varepsilon = \frac{u_*^3}{k\left(z + z_0\right)},$$

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and,

$$\tau_{13} = \tau_{uw} = u_*^2 \left(1 - \frac{z}{h}\right)^{3/2} \approx u_*^2,$$

with z_0 the roughness length and *k* the von Karman constant (chosen as 0.4) (Rodean, 1996, pages 59-64).

At points where the horizontal shear is greater than the vertical shear, the effects of the horizontal shear are treated in a manner analogous to the treatment for vertical shear. Under these circumstances similar equations are used with the y and z coordinates interchanged and v and w components also interchanged. At present the effects of a non-zero W on turbulent winds is not considered.

The mean wind, computed by QWIC-URB on a grid, is interpolated to the particle position using an inverse distance weighting from adjacent grid cell centers. With a nearby wall, the perpendicular distance to the wall is used instead of the distance to the corresponding cell center.

Reflection on walls and ground surfaces is treated as though the particles were elastic. Reflection is calculated in the direction that would give the largest penetration into a wall during the time step. The particle is moved a distance from the wall equal to the calculated penetration and the sign of the random velocity component is reversed.

Average concentrations, normalized to unit release, are estimated by:

$$\frac{\chi_{i,j,k}}{Q} = \sum \frac{dt}{n_{tot} dx_b dy_b dz_b},$$

where the sum is over all particles that are found within the sampling box *i,j,k* during the sampling time. n_{tot} is the total number of particles released during the computations, dx_b is the sampling box size in the x – direction, dy_b is the sampling box size in the y – direction, and dz_b is the sampling box size in the z – direction.

3. Discussion

Figure 1 shows the particle trajectories that result after eight seconds when 500 particles are simultaneously released upwind of a building. The particles have moved slowly toward the building where they begin to spread out and the large values of ε near the wall produce large random components of the wind. Despite the fact that the large-scale wind was one meter per second and the building dimensions are only 6 meters in each direction,

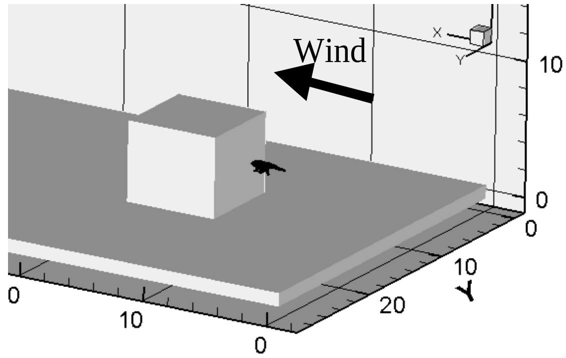

Figure 1. Particle trajectories for an upwind release 8 seconds after the release start time.

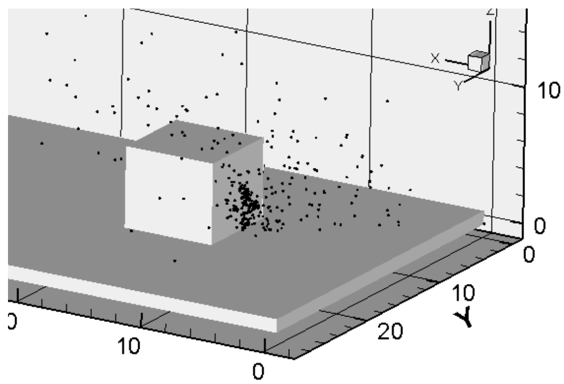

Figure 2. Particle positions after 30 seconds.

particles persist in the vicinity of the building for tens of seconds, trapped in the upstream rotor. Figure 2 shows the particle positions after thirty seconds. The turbulent winds produce dispersion of particles in both the upwind and downwind directions.

4. Future work

We plan to compare the model results to single building, wind-tunnel tracer data. We also plan to extend the turbulence treatment to include the effects of non-zero vertical wind components and improve the treatment of horizontal inhomogeneities.

5. References

Pardyjak, E. R. and M. J. Brown, 2001, Evaluation of a Fast-Response Urban Wind Model – Comparison to Single-Building Wind Tunnel Data, LA-UR-01-4028, Los Alamos National Laboratory.

Rodean, H. C., 1996, "*Stochastic Lagrangian Models of Turbulent Diffusion,"* The American Meteorological Society, 82 pages.