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**ODOUR SOURCE IDENTIFICATION IN A COMPLEX FLOW ENVIRONMENT
 USING A PARTICLE TRAJECTORY MODEL**

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Abstract

This paper presents a methodology that generates complex flow fields based on the NavierStokes equations for fine-mode trajectory modelling. Initial u- and v-component of wind is input to the model from an onsite weather station on a 2-minute resolution. The perturbed flow is then calculated in an iterative fashion until the numerical solution converges. The results are then be stored and the next initial u- and v-component of wind will be input from the anemometer. Each solution is stored and converted for use in a particle trajectory model.

Preliminary results indicate that the complex flow model approximates results from more sophisticated models. A real-world test case also demonstrates the usefulness of this methodology as a quick tool in identifying potential odour sources.

1. Introduction

Back trajectories are a useful tool for facilities to identify odour sources for timely management actions to be implemented, thereby minimising potential offsite complaints. However, the most commonly used trajectory models such HySplit (Stein *et al*, 2015) cannot accurately depict particle motion in industrial situations where air flow is almost always subject to interference from structures. In addition, the spatial and temporal resolution of the data used in these models are often too coarse to resolve the flow in these situations. Computational Fluid Dynamics (CFD) models are often used to resolve flows in these situations. However, these models are computationally intensive and cannot be used on a near real-time basis.

A finite difference fast solver for the steady state Navier Stokes equations is presented in this paper. The results of this model are compared to those obtained from

the QUIC-URB fast response urban dispersion model (Pardyjak and Brown, 2002; 2003). Finally, a test case is examined for a waste water treatment facility.

2. Materials and methods

The Navier-Stokes equation can be written in vector form as:

$$\frac{\partial u}{\partial t} + u \cdot \nabla u = -\frac{\nabla P}{\rho} + \nu \nabla^2 u$$

where u is the fluid velocity, p is the fluid pressure, ρ is the fluid density and ν is dynamic viscosity. These equations describe how the velocity, pressure, temperature, and density of a moving fluid are related.

The numerical solution of the Navier-Stokes equations involves discretisation of simple differential equations and applying it to the continuous (Navier-Stokes) equations. The finite difference method is used for the discretisation and follows the methodology of Griebel et al. (1998). Beginning at time $t = n$, with given initial values for u and v , time is increased by δt until a final time ($t = n + \Delta n$) is reached. The time stepping loop commences by first performing time discretisation of the terms $\partial u / \partial t$ and $\partial v / \partial t$ in equations 1 and 2, thereby obtaining the following form:

$$u^{(n+1)} = F^n - \delta t \frac{\partial p^{(n+1)}}{\partial x} \quad (1a)$$

$$v^{(n+1)} = G^n - \delta t \frac{\partial p^{(n+1)}}{\partial y} \quad (1b)$$

where

$$F = u^n + \delta t \left[\frac{1}{Re} \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - \frac{\partial(u^2)}{\partial x} - \frac{\partial(uv)}{\partial y} + g_x \right] \quad (2a)$$

$$G = v^n + \delta t \left[\frac{1}{Re} \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - \frac{\partial(uv)}{\partial x} - \frac{\partial(v^2)}{\partial y} + g_y \right] \quad (2b)$$

The derivatives in Eqn. 2a and 2b are discretised in two dimensions using finite differencing:

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = \frac{u(x_{i+1,j}) - 2u(x_{i,j}) + u(x_{i-1,j}) + u(x_{i,j+1}) - 2u(x_{i,j}) + u(x_{i,j-1}))}{\delta y^2}$$

$$\frac{\partial(uv)}{\partial y} = \frac{1}{\delta y} \left(\frac{(v_{i,j} + v_{i+1,j})(u_{i,j} + u_{i,j+1})}{2} - \frac{(v_{i,j-1} + v_{i+1,j-1})(u_{i,j-1} + u_{i,j})}{2} \right)$$

$$\frac{\partial(u^2)}{\partial x} = \frac{1}{\delta x} \left(\left(\frac{u_{i,j} + u_{i+1,j}}{2} \right)^2 - \left(\frac{u_{i-1,j} + u_{i,j}}{2} \right)^2 \right)$$

Substituting equations 2a and 2b into the continuity equation and rearranging, gives the Poisson equation for pressure

$$\frac{\partial^2 p^{(n+1)}}{\partial x^2} + \frac{\partial^2 p^{(n+1)}}{\partial y^2} = \frac{1}{\delta t} \left(\frac{\partial F^{(n)}}{\partial x} + \frac{\partial G^{(n)}}{\partial y} \right) \quad (6)$$

The following boundary values are required for the discretised momentum equations:

- Buildings and structures - No-slip conditions are set for obstacles within the flow field. This means that velocities equal zero on these boundaries.
- Inflow – u and v velocities from the weather station are explicitly given as an inflow boundary condition.
- Outflow – the normal derivatives of u and v are set to zero at the boundary, thereby setting velocity values along the boundary to equal to their neighbouring values inside the domain.

The complex flow model described above requires the following initial inputs:

- Fine temporal resolution u- and v- wind components;
- 2-dimensional array with structures identified by their heights and non-structures (i.e. ground) identified as zero; and
- Reynolds number for each model setup.

Comparison of near-surface wind fields generated by the Envirosuite code with those generated by QUIC-Urb (Pardyjak and Brown, 2003) for initial southwesterly flow shows excellent agreement, with both models showing establishment of a twin wake eddy downwind of the obstacle (Figure 1).

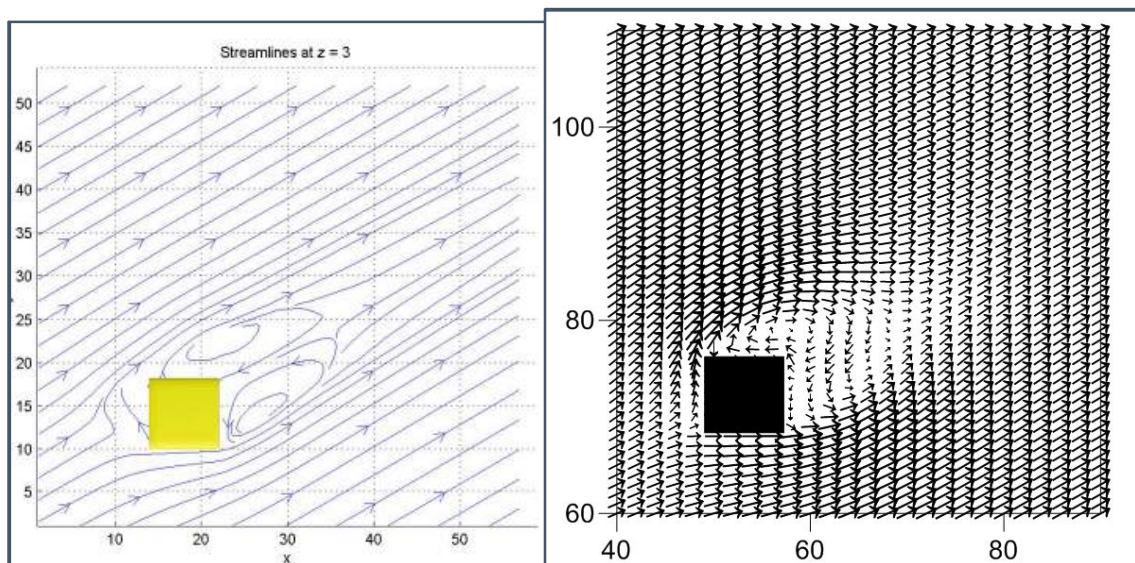


Fig.1.: Streamlines of flow out the south west around a single cube using QUIC-URB (after Pardyjak and Brown 2003) (Left) and flow vectors out the south west around a single cube using the complex flow model.

The trajectory model is based on the kinematic trajectory model presented in D'Abreton (1996) and D'Abreton and Tyson (1996). The model is Lagrangian, with atmospheric motion being described in terms of individual air parcels moving with air streams. The model uses the explicit method of integration defined by

$$x(t + dt) = x(t) + V[x(t)]dt$$

Where $x(t+dt)$ is the new three-dimensional particle position at $t+dt$, $x(t)$ is the old position and $V(t)$ is the parcel velocity vector ($V=[u,v,w]$) which is the sum of the mean and turbulent components:

$$V = \bar{V} + V'$$

The mean component ($\bar{V}$) is obtained from the gridded three-dimensional derived wind fields, interpolated to produce u -, v - and w -components at the precise location of the particle for each time step. The trajectory model estimates the turbulent component (V') from the standard deviations of the fluctuating velocities (σ_u , σ_v and σ_w). These were derived from the definition of TKE (where TKE was produced as an output from the complex flow model). Solving for σ_u and σ_v gives:

$$\sigma_u = \sigma_v = \sqrt{\frac{2}{3}TK}$$

The turbulence partition between the vertical and horizontal components is defined through the turbulence anisotropy ratio. A factor of 0.18 is assumed from the literature.

The time for the model to converge (reach a solution) depends on the size of the domain and the spatial resolution of the mesh. Typically, a domain of 200 m x 200m (at 4 m resolution) takes approximately 5 minutes to converge.

3. Results and discussion

A wastewater treatment facility has been selected to test whether this methodology can be used to identify odour sources in an area with complex flow. Figure 2 shows the facility with potential odour sources identified as well as three e-nose odour monitors, which were developed and deployed by Odotech (Canada). Each e-nose incorporates 16 metal oxide sensors, some of which are in duplicate, and which respond to the presence of different groups of odorous compounds. The net result is that the e-noses respond to a broad range of odour types. Those deployed in this wastewater treatment facility had been in place for over 3 years and were not configured to provide odour fingerprints, which can help identify odour types and sources, unlike more recent units.

Building heights were entered into the model and 2-minute wind data (between 0.9 m/s and 4.5 m/s) recorded by means of 2D sonic anemometer at the on-site meteorological station, was used to determine inflow conditions for the complex flow model. Note that turbulence measurements were not used in the model, thereby allowing the model to generate spatially varying turbulence fields.

Figure 3 shows backward trajectories for four separate times. Trajectories for 10 April 22:42 (upper left) show that the high odour concentrations measured at EN03 is most likely due to aeration while the slightly lower measured odour at EN01 is most likely due to the secondary clarifier. Trajectories for 10 April 23:34 (upper right) show that sludge storage is responsible for the odour measured at EN01. By contrast, odour at EN03 may be due to emissions from the secondary clarifier, sludge thickening and/or sludge storage. Trajectories for 11 April 15:38 (lower left) show that the elevated odour concentration measured at EN03 may not be due to emissions from the WWTP but rather a metal casting facility to the west. The odour measured at EN01 may be due to emissions from the secondary clarifier and/or aeration. The odour concentration measured at EN03 on 6 May 17:32 (lower right) may be partly due to offsite emissions to the west and emissions from the secondary clarifier. By contrast, odour measured at EN01 may be due to emissions from sludge thickening or an unidentified offsite source. Measured odour at EN02 is not due to WWTP emissions, but rather from manufacturing facilities to the west.

More recent e-nose models available to the authors are configured to readily provide sensor-specific data and to analyse signals to identify a broad odour type – the specificity will depend on the nature of the odour, its intensity and the extent to which odours of different types are mixed in plumes.

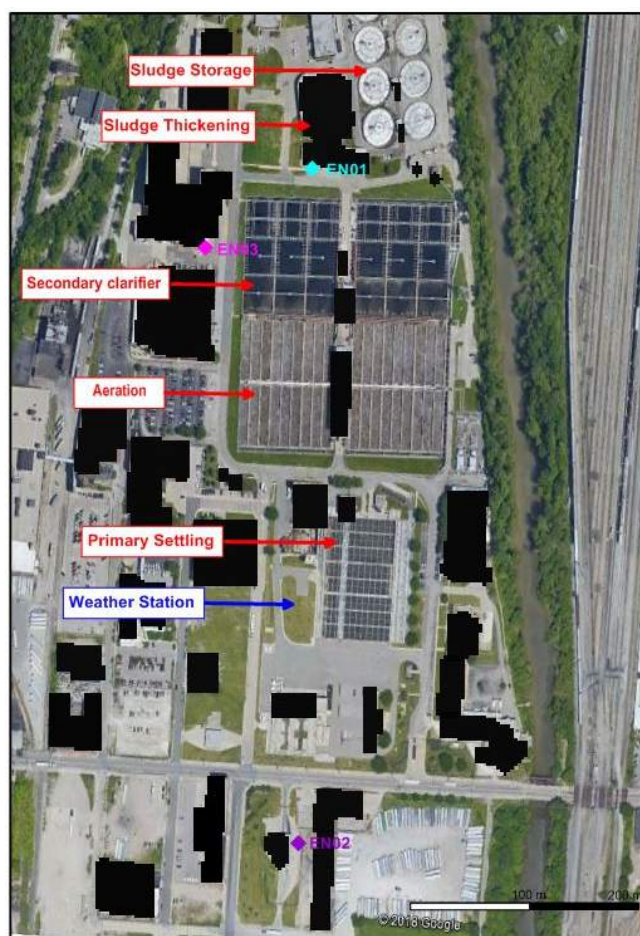


Fig. 2.: Location of potential odour sources, weather station and H₂S monitors. Buildings considered in the model are also indicated.

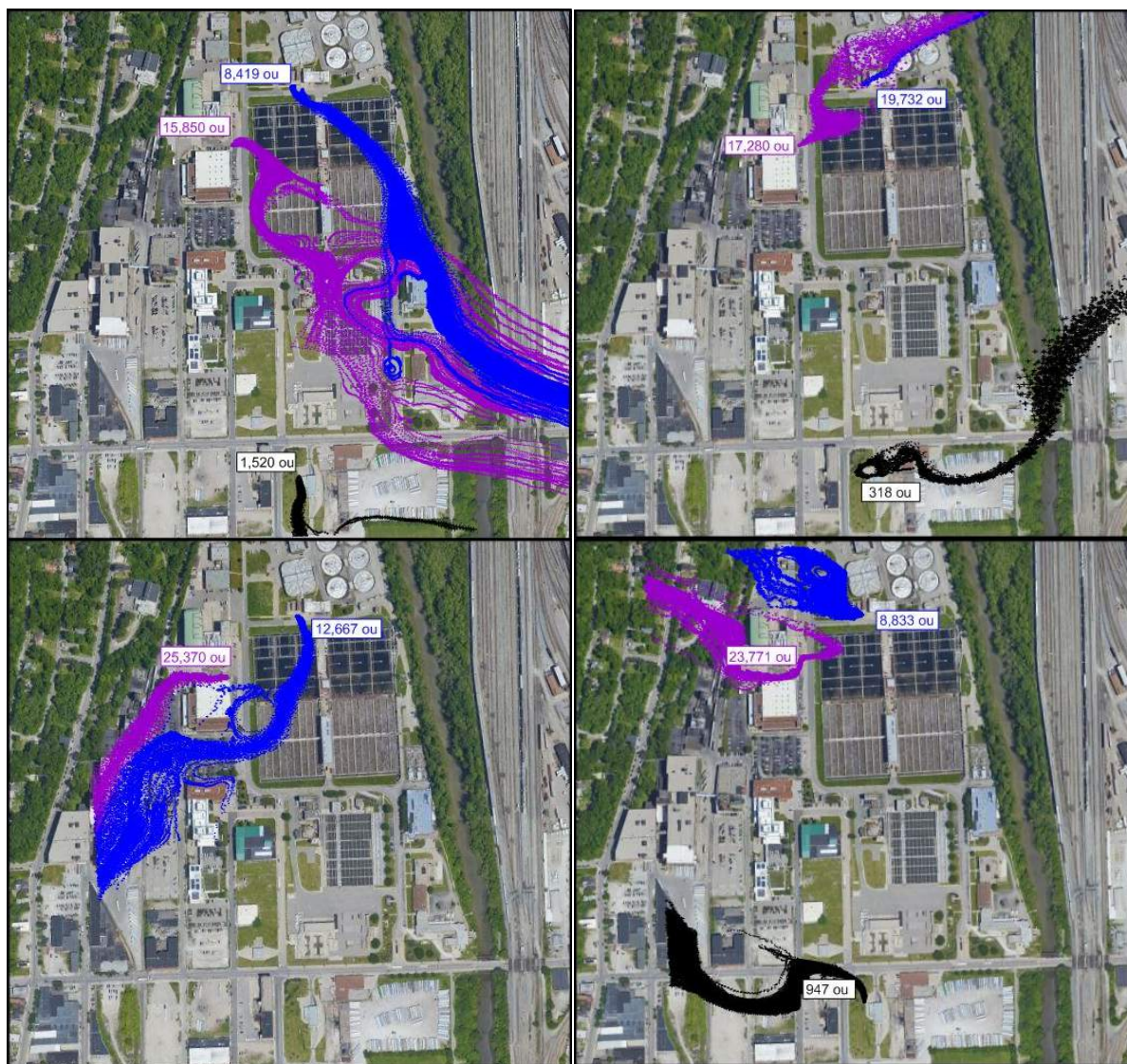


Fig. 3.: Backward trajectories for 10 April 22:42 (upper left), 10 April 23:34 (upper right), 11 April 15:38 (lower left) and 6 May 17:32 (lower right). Measured odour concentrations at each monitor is indicated on the figures.

4. Conclusions

A finite difference fast solver to estimate flow in a complex regime was presented in this paper. This model allows near real-time solution of complex flow from a single onsite weather station, with execution times within a few minutes. In contrast to existing trajectory models, the complex flow model can be used to drive a particle trajectory model to determine near-field transport in disturbed flow.

A case study shows that in principle, odour sources can be identified from a combination of trajectories under complex flow conditions. In particular, offsite odour sources may be identified, thereby averting the need for mitigatory actions and even potential legal issues.

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