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Ministry
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A Model for Buoyant Puff Dispersion in Urban Areas

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Introduction

- The Urban Dispersion Model (UDM) was developed to satisfy an MOD requirement for prediction of toxic contaminants in urban areas from 10 m to 10 km.
- A Gaussian puff model combined with wind tunnel data approach was adopted to:
  - Provide **rapid** predictions of urban dispersion;
  - Enable a wide variety of releases to be simulated: instantaneous, continuous, static or moving.

(Hall)

Introduction

- UDM is a component of the Hazard Prediction and Assessment Capability, and has been continuously developed to handle a wider range of sources.
- A first-order buoyant puff model has now been developed.
- The model enables UDM to predict the dispersion of material with significant buoyancy resulting from:
  - The density of the material;
  - Heat input.

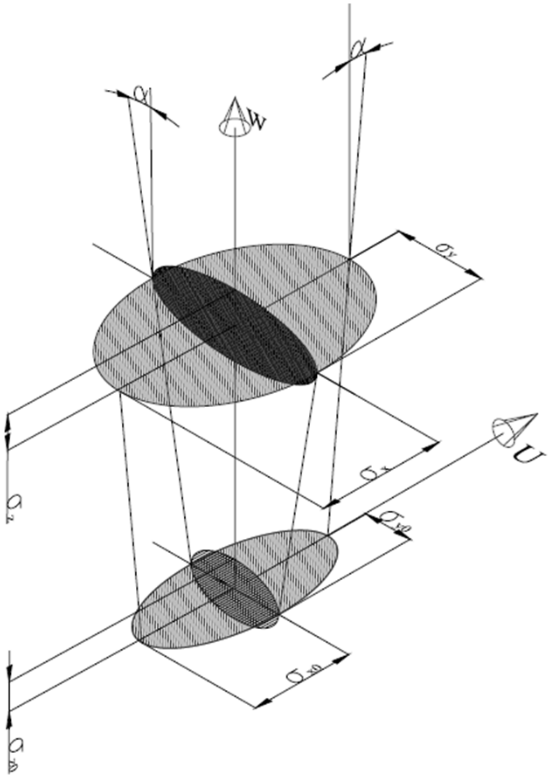
Basis of Model

- A literature review by Hall and Spanton showed:
  - No simple model existed for predicting the buoyant rise of puffs of arbitrary size and shape;
  - There was no data from systematic experiments on buoyant puff-rise;
  - There was no data on the dispersion of buoyant puffs or plumes within or just above the urban canopy.
- They concluded a model could be developed from theory relating to atmospheric thermals in still air[1].

[1] Developed by Csanady (1973), Turner (1973), Scorer (1978) and Fannelop (1994).

Model Assumptions

- The first-order approach assumes the following:
  - There is no initial energy apart from the buoyancy;
  - The Boussinesq approximation holds;
  - The puff forms are self-similar at all heights;
  - There is no initial vertical acceleration of the puff;
  - The source of buoyancy is preserved;
  - The rate of lateral spreading is equal across both coordinates of the puff.



Puff-rise in Open Terrain

- The model predicts puff spread (σ) and vertical velocity (w).
- Puff shapes are assumed to vary linearly between the extremes of axisymmetric and line forms:

$$\text{Axisymmetric puff}: \frac{\sigma_x}{\sigma_y} = 1 \quad , \quad \text{line puff}: \frac{\sigma_x}{\sigma_y} < 0.1 \ \text{ or } \ \frac{\sigma_x}{\sigma_y} > 10$$

- The puff spread is given by:

$$\frac{d\sigma}{dz} = F(\alpha) \quad \text{where } F(\alpha) \text{ depends upon the puff shape}$$

Puff-rise in Open Terrain

- The buoyancy forces for axisymmetric and line thermals are F_0 and F_L respectively:

$$F_0 = \frac{g}{\pi}\frac{\Delta\rho}{\rho}V \quad \text{and} \quad F_L = \frac{g}{\pi}\frac{\Delta\rho}{\rho}V$$

where ρ is density and internal volume V depends upon puff shape.

- The vertical velocity is given by:

$$w = C\left(g\frac{\Delta\rho}{\rho_0}R\right)^{0.5} \quad \text{where } C \text{ is a constant and } R \text{ the lateral spread}$$

Puff-rise in Open Terrain

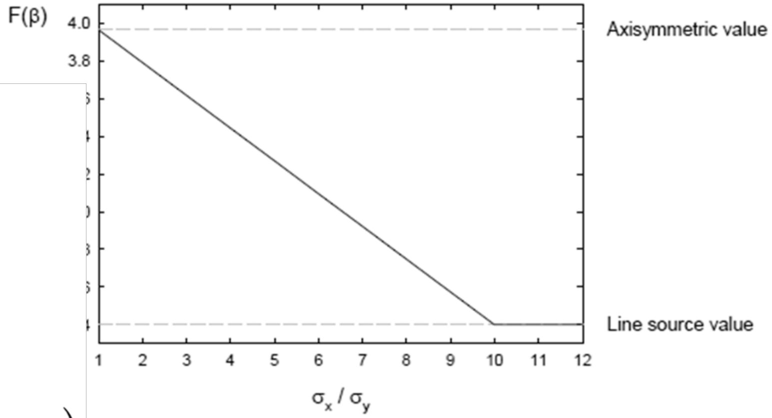
- The common form for all puffs derived by Hall and Spanton is:

$$w = F(\beta)\left[\frac{F(\gamma)Q}{\sigma_x\sigma_y}\right]$$

$F(\beta) = \text{constant depending on puff shape,}$

$F(\gamma) = \text{volume scale factor} = \dfrac{0.74\,\min(\sigma_x, \sigma_y)}{\sigma_z}$

$Q = \text{initial heat release in MJ, and } F_0 = 8.9Q$



Merging Buoyant Puff-rise with Dispersion by Turbulence

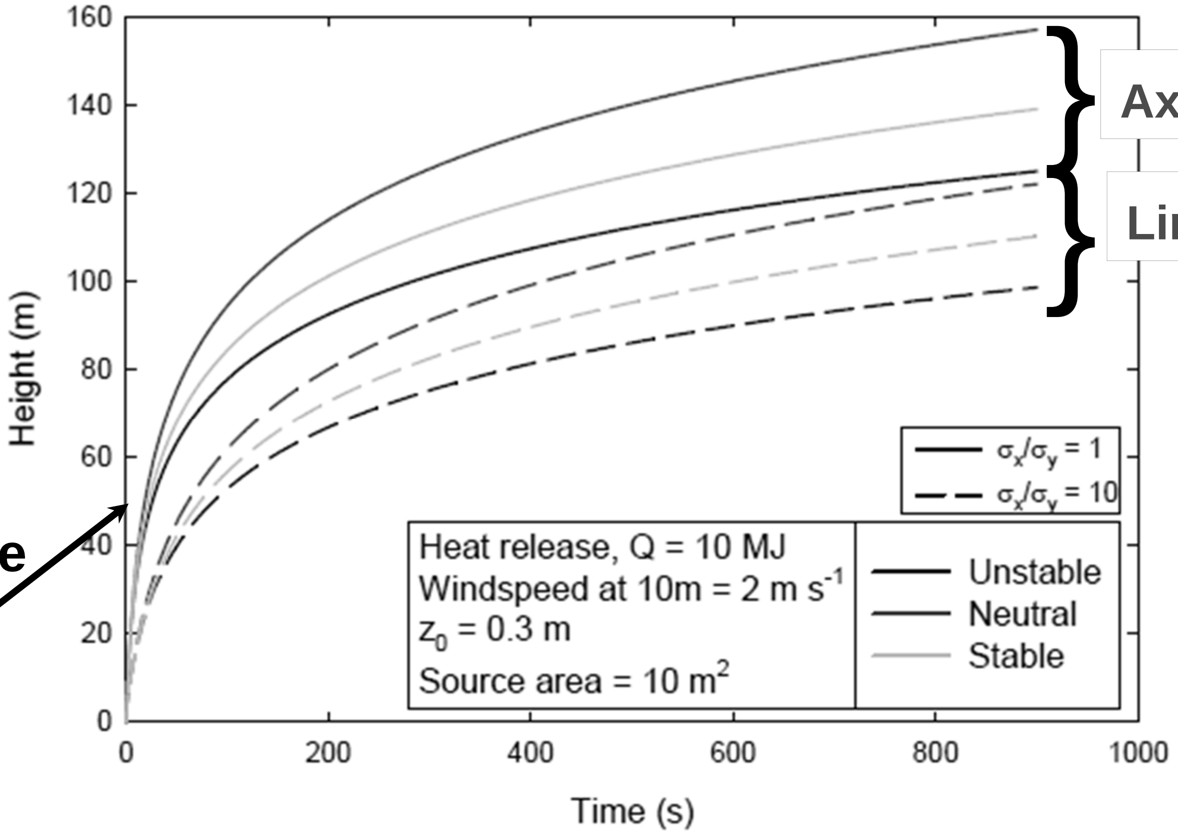
- UDM merges turbulence and array dispersion components by summing in quadrature:

$$\sigma_{total}^{2} = \sigma_{turbulence}^{2} + \sigma_{array}^{2}$$

- The interaction between buoyant puff-rise and spread by turbulent dispersion is accounted for by using:

$$\sigma(t + \Delta t) = \sigma(t) + \left(\Delta\sigma_{b}^{2} + \Delta\sigma_{total}^{2}\right)^{0.5}$$

Example output



Axisymmetric

Line

Rapid rise initially

Over-lapping puffs

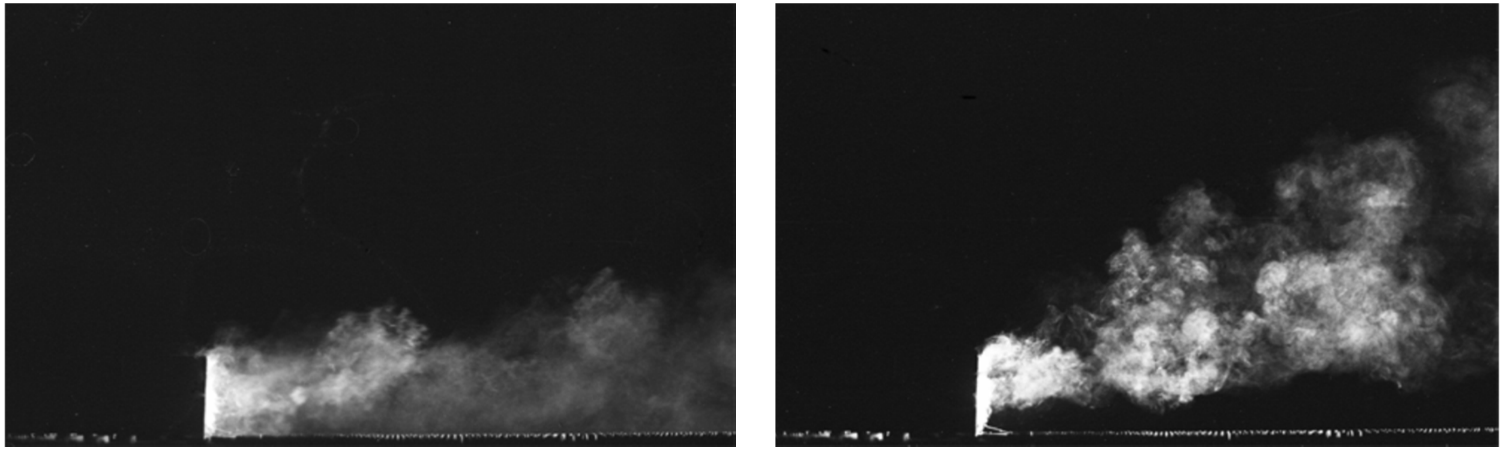
- When puffs over-lap during simulations, their varying densities must be accounted for.
- Buoyancy enhancement is assumed proportional to the additional concentration of over-lapping puffs.
- Puff buoyancy is enhanced by the factor $F(\delta)$:

$$F\left(\delta\right)=\frac{C_{\mathrm{total}}}{C_{\mathrm{max}}}$$

Where C_{total} is total cumulative concentration at the puff centre, and C_{max} the concentration at the puff centre.

Interaction with Isolated Obstacles

- Experiments on plumes by Hall *et al.* have shown that buoyant plumes will lift-off:

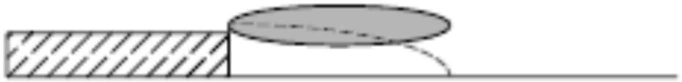


Neutral buoyancy High buoyancy

Interaction with Isolated Obstacles

- Interactions are accounted for by development of the puff partitioning in UDM to incorporate buoyant puffs:

First Time Step - Wake Detrained Fraction (as Present UDM)



First Time Step - Detrained Fraction From Buoyant Rise

First Time Step - Detrained Fractions Merged and Positioned

Conclusions

- A simple first-order model has been developed for thermal plume and buoyant puff-rise:
    - Its behaviour is in accordance with observations;
    - It integrates the prediction of buoyant puff-rise with dispersion due to turbulence;
    - It accounts for changes in puff-rise velocity due to changes in puff depth and over-lapping puffs;
    - It models interactions with urban arrays and obstacles.

Questions?

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