CFD Simulation of inverse plumes for identifying a stationary point source in low wind stable conditions

Amir Ali Feiz, Emerson Barbosa, Sarvesh Kumar Singh, Mohamed Sellam, Grégory Turbelin, Pierre Ngae, Hambaliou Baldé, Amer Chpoun

University of Evry Val-d'Essonne, France

Laboratory for Mechanics and Energetics (LMEE)*

Fluid Mechanics and Environment Group (MFE)

*http://lmee.univ-evry.fr

Introduction

In low-wind stable conditions,

✓ plume meandering is effective

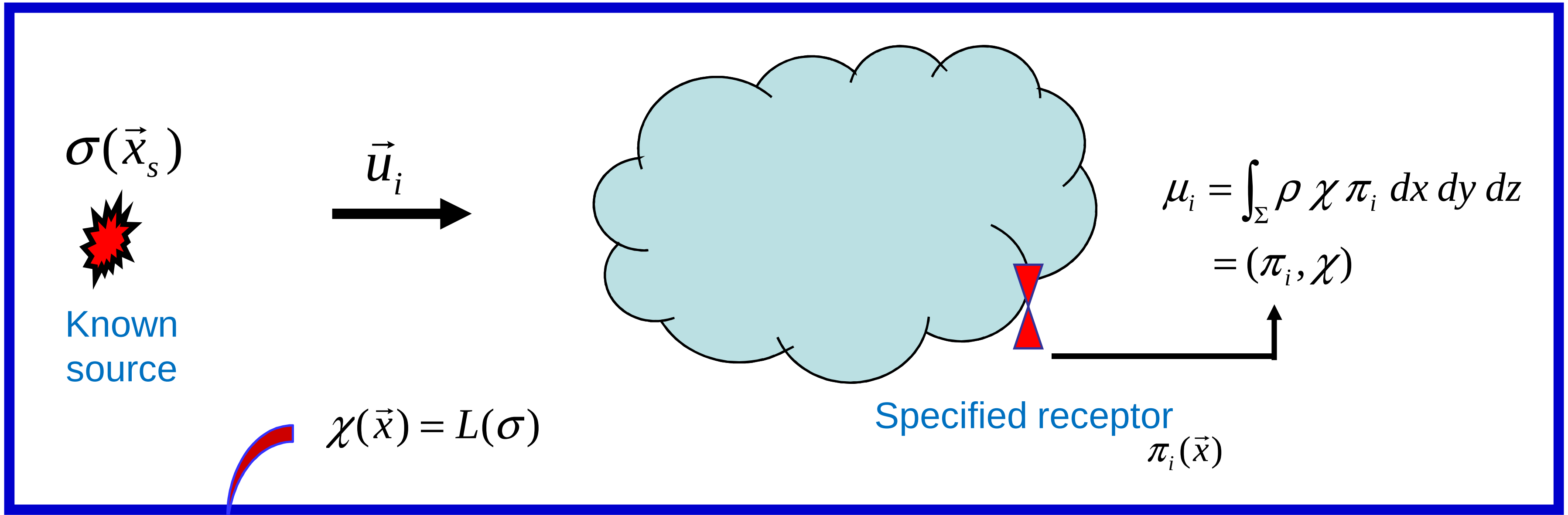
✓ diffusion of pollutant is irregular and indefinite

✓ the turbulence and dispersion characteristics of the lower atmosphere is not properly defined

✓ the observed concentration distribution is generally multi-peaked and non-Gaussian

➡ **CFD Eulerian/Analytical models** are used to simulate the **inverse plumes** for identifying a stationary point source in low wind stable conditions

Forward Modelling



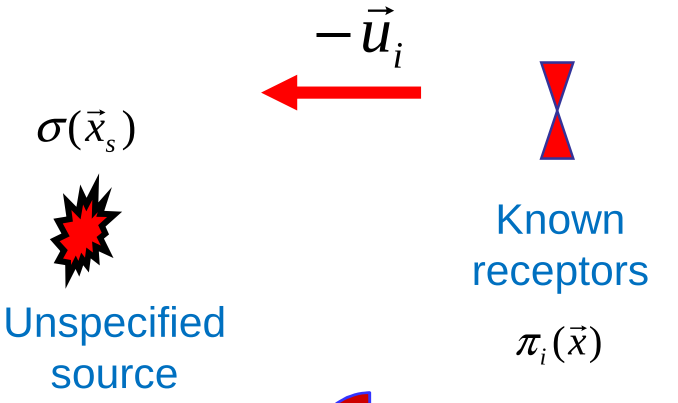
$$\mathbf{u}.\nabla\chi = \frac{1}{\rho}\nabla\left(\rho\mathbf{K}.\nabla\chi\right) + \sigma$$

(**forward transport equation for a continuous release of a non-reactive tracer**)

Problem: For a given source distribution, determine the concentration at an arbitrary receptor location

Backward Modelling (1)

addressed with adjoint of the dispersion models



Symmetric relationship for forward transport and adjoint steady-state transport

$$-\mathbf{u}.\nabla r_i = \frac{1}{\rho}\nabla\left(\rho\,\mathbf{K}.\nabla r_i\right) + \pi_i \qquad r_i = L^*(\pi_i)$$

(adjoint transport equation)

Backward Modelling (2)

Since measurements are made at point locations, they are associated with sampling function defined by Dirac notation

$$\mu_i = \int_\Sigma \rho \, \chi \, \pi_i \, dx \, dy \, dz$$

integrated mixing ratio at receptor location

$$= (\pi_i, \chi) = (\pi_i, L(\sigma)) = (L^*(\pi_i), \sigma)$$

$$= (r_i, \sigma)$$

$$= \int_\Sigma \rho \, \sigma \, r_i \, dx \, dy \, dz$$

r_i is simulated by CFD model

In general, any source estimation technique is driven by simulation of retroplume

Dataset (1)

Idaho Falls dataset (Sagendorf & Dickson, 1974), near Idaho National Engineering Laboratory (INEL), USA

- Release type: Open-area, continuous release, release height for all experiments was 1.5 m

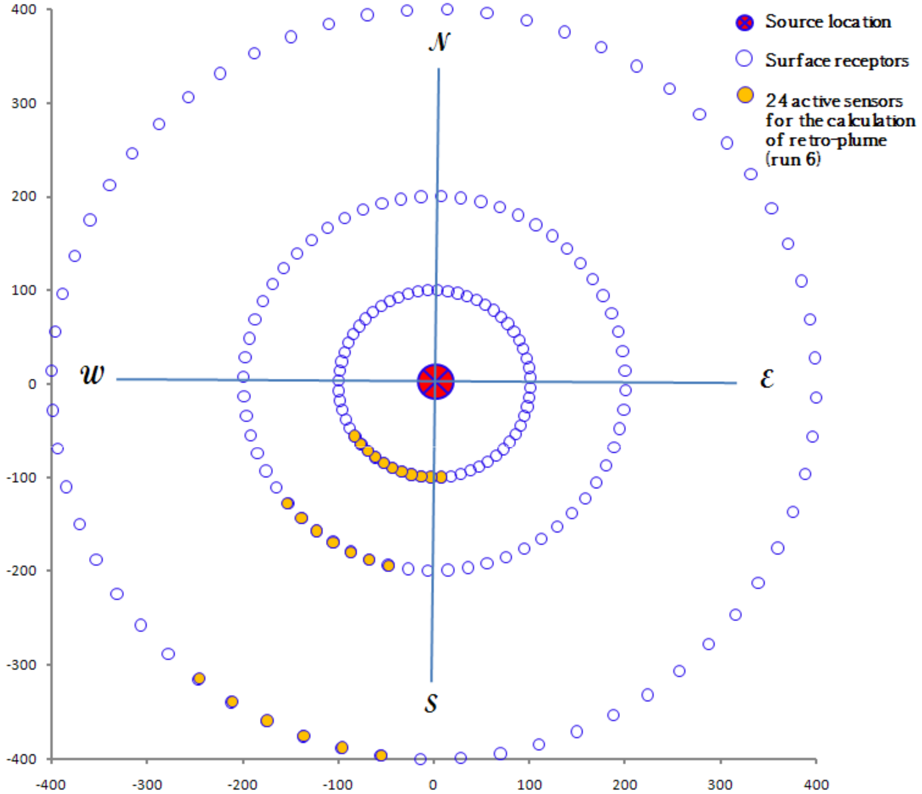
- Dispersion environment: Relatively flat area, stable inversion conditions

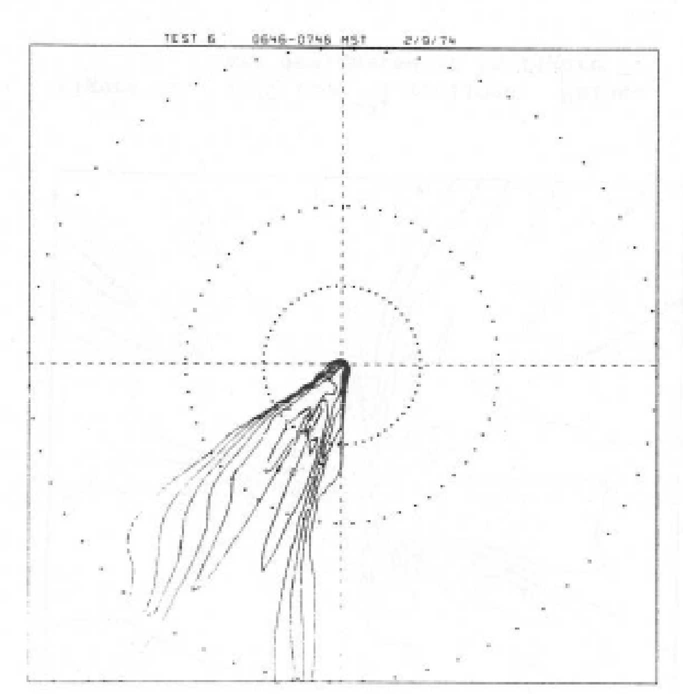
- Time study conducted: Winter/Spring 1974 , 11 days of experiments, each experiment 1 hour SF_6 releases, all in stable conditions

- Sampling network: Samplers every 6 degrees at distances of 100 m, 200 m, 400 m at height of 0.76 m

- Meteorological data: Ws, Wd and Temp. at 1, 2, 4, 8, 16, 32, and 61 m; Range of Ws: 0.75-1.92 m/s

Dataset (2)





Sagendorf & Dickson, 1974

➡ Experimental observations are taken for a single trial (**run-6**), which corresponds to a large extent of concentration meandering

Results

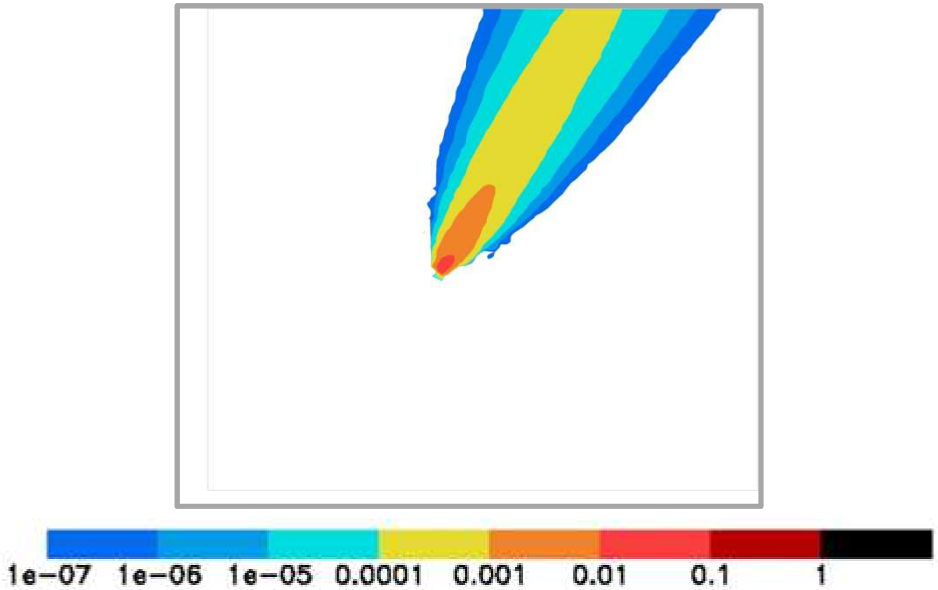
✓ Dispersion of inverse plumes of passive tracer SF6 from the receptors is given by CFD dispersion model, **PANEPR-Retro** (Fluidyn™)

✓ The inverse plumes are defined as solutions of the adjoint model of dispersion

✓ **PANEPR** compute the concentration at all active receptors (run 6 of Idaho Falls experiments) assuming:

- ✓ the intensity of release as unity
- ✓ the concentration in backward mode by simply changing the wind direction by 180°

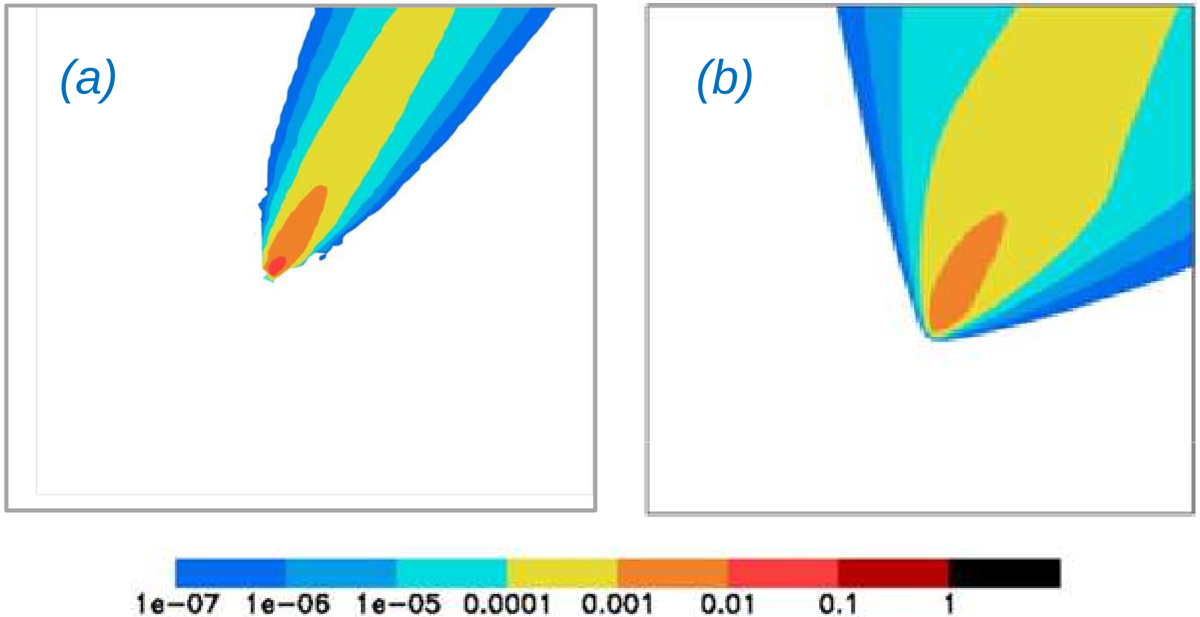
Results (1)



PANEPR simulation of inverse plume for receptor 1 in run-6 of Idaho Falls dispersion experiment. Predicted concentration is shown in terms of mass fraction of SF6

- ✓ Retro-plumes distribution is almost identical whith respect to each receptor
- ✓ Max conc. is at the receptors, in fact due to Dirac notation, retro-plume at receptor is almost singular
- ✓ The concentration is dispersed mainly along wind direction
- ✓ This is also compared with retro-plumes obtained from an analytical model (Sharan et al., 1996) with coupled plume-segment approach with Luhar (2011) dispersion parameterization (made available by Singh)

Results (2)



A comparison of inverse plumes for receptor 1 using (a) 3D CFD model (PANEPR), (b) 3D analytical model along plane of release height above the ground

✓ An inversion technique based on a theory called « Renormilized data assimilation » is used in order to reconstruct the point emission source location → will be presented in next session of Harmo-15 (H15-58)

Comments

Analysis of models results provided clues for understanding of ...

- with PANEPR-Retro, the source was poorly estimated approx. 70m away from true source position
- with analytical model, the source was still predicted better, 30m away from true release
- even, a severe under-prediction (factor of 20) of source strength is observed with both the models
- this refers that in actual the retro-plume are still over-predicted
- with sensitivity study, this uncertainity is resolved to some extent by accounting the effective release height and receptor's height
- still it requires a lot attention to improve dispersion simulation in low wind conditions

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Thank you for your attention!

Contact: amirali.feiz@univ-evry.fr

http://lmee.univ-evry.fr