Reconstructing the Height of an Unknown Point Release in Low Wind Stable Conditions

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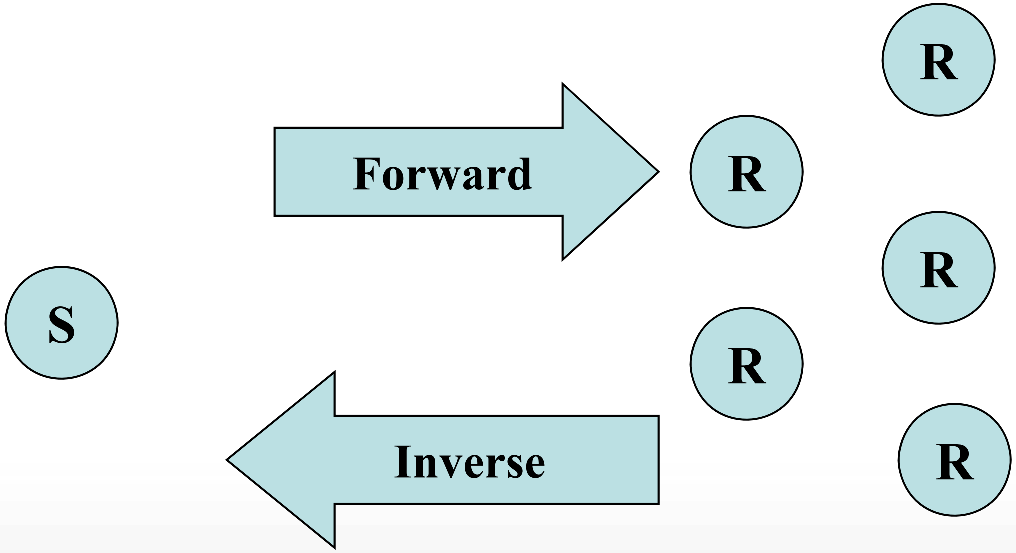
Source Reconstruction

- Concentration measured/predicted is a function of source characteristics.

$$\boldsymbol{\mu}(\mathbf{x},t) = \mathbf{F}(\boldsymbol{\sigma}).$$

S – Source and R- Receptor



Why Low-wind Stable conditions?

- Pollutant dispersion is subjected to the frequent meandering and large wind variability
- The diffusion of pollutant is irregular and indefinite.
- Observed concentration distribution is multi-peaked and non-Gaussian.
- Pollutants do not travel far from source.

Why elevated release?

In stable conditions, concentration measurements are sensitive to…

- Height of release.
- Height of receptors.

This affects the model representativity and retrieval accuracy.

Parametric Estimation Problem

- Four unknown parameters:
  - Location(x_0, y_0, z_0)
  - Emission Rate (q)

Renormalization Inversion Technique

- The correspondence between emission function *s(x,y,z)* and measurement μ_i is,

$$\mu_i(x,y,z_r) = \int_{\Sigma} s(x,y,z)\,a_i(x,y,z)\,dx\,dy\,dz = (s,a_i)$$

$$s(x,y,z) = q\,\delta(x-x_0)\,\delta(y-y_0)\,\delta(z-z_0)$$

Derivation of Retro-plumes

- The forward transport equation for a continuous release of a non-reactive tracer is

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

$$\boxed{\sigma(x,y,z)=\frac{s(x,y,z)}{\rho}}$$

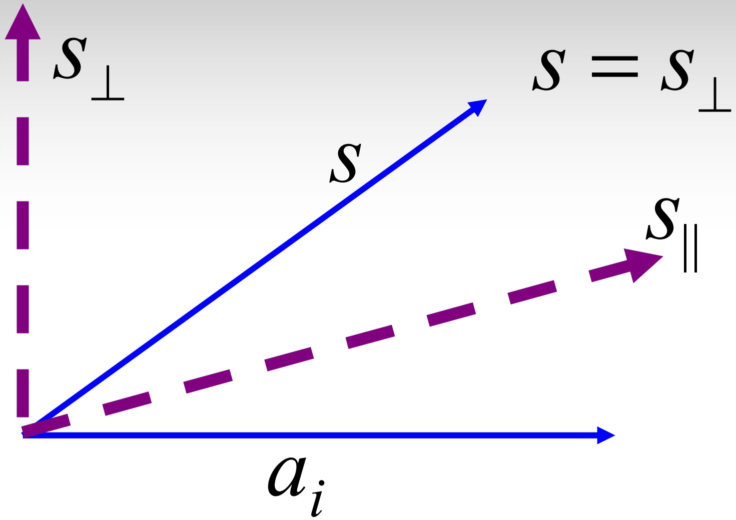
- The backward transport equation is $-\mathbf{u}.\nabla r_i = \frac{1}{\rho}\nabla\left(\rho\mathbf{K}.\nabla r_i\right)+\pi_i$

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

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

$$a_i(x,y,z) = r_i(x,y,z)$$

Classical Identification Theory



$$s = s_\perp + s_\parallel$$

$$\left(s, a_i\right) = \mu_i$$

$$s_\parallel(\mathbf{x}) = \sum_{i=1}^{n} \lambda_i \, a_i(\mathbf{x})$$

$$\mathbf{H} = [(a_i, a_j)] \quad and \quad \lambda = \mathbf{H}^{-1}\boldsymbol{\mu}$$

Distributed Emissions

$$\boxed{s_\parallel = \boldsymbol{\mu}^{\mathrm{T}}\mathbf{H}^{-1}\mathbf{a}}$$

Associated with singularities in case of point measurements

Renormalization Theory

$$(s,a_i)_\varphi = \int_\Sigma s\,\frac{a_i}{\varphi}\,\varphi\,d\mathbf{x} = \int_\Sigma s\,a_{\varphi i}\,\varphi\,d\mathbf{x}$$

Renormalize weight function

$$in\ which\ a_{\varphi i}(\mathbf{x}) = \frac{a_i(\mathbf{x})}{\varphi(\mathbf{x})}$$

= Renormalize adjoint function

Optimality Criterion

$$\varphi(x,y,z) \geq 0$$

$$\int_\Sigma \varphi(x,y,z)\,dxdydz = n$$

$$\mathbf{a}_\varphi(x,y,z)^{\mathrm{T}}\mathbf{H}_\varphi^{-1}\mathbf{a}_\varphi(x,y,z) \equiv 1$$

$$\boxed{s_{\|\varphi}(\mathbf{x}) = \boldsymbol{\mu}^{\mathrm{T}}\mathbf{H}_\varphi^{-1}\mathbf{a}_\varphi(\mathbf{x})}$$

$$where\quad \mathbf{H}_\varphi = \left(a_{\varphi i}, a_{\varphi j}\right)_\varphi$$

Point Source Retrieval

$$\mu_i = q a_i(\mathbf{x}_0) = q\varphi(\mathbf{x}_0) a_{\varphi i}(\mathbf{x}_0)$$

The source estimate is,

$$s_{\|\varphi}(\mathbf{x}) = q\varphi(\mathbf{x}_0) s_0(\mathbf{x}) \quad \textit{where,} \quad s_0(\mathbf{x}) = \mathbf{a}_\varphi(\mathbf{x}_0)^{\mathrm{T}} \mathbf{H}_\varphi^{-1} \mathbf{a}_\varphi(\mathbf{x})$$

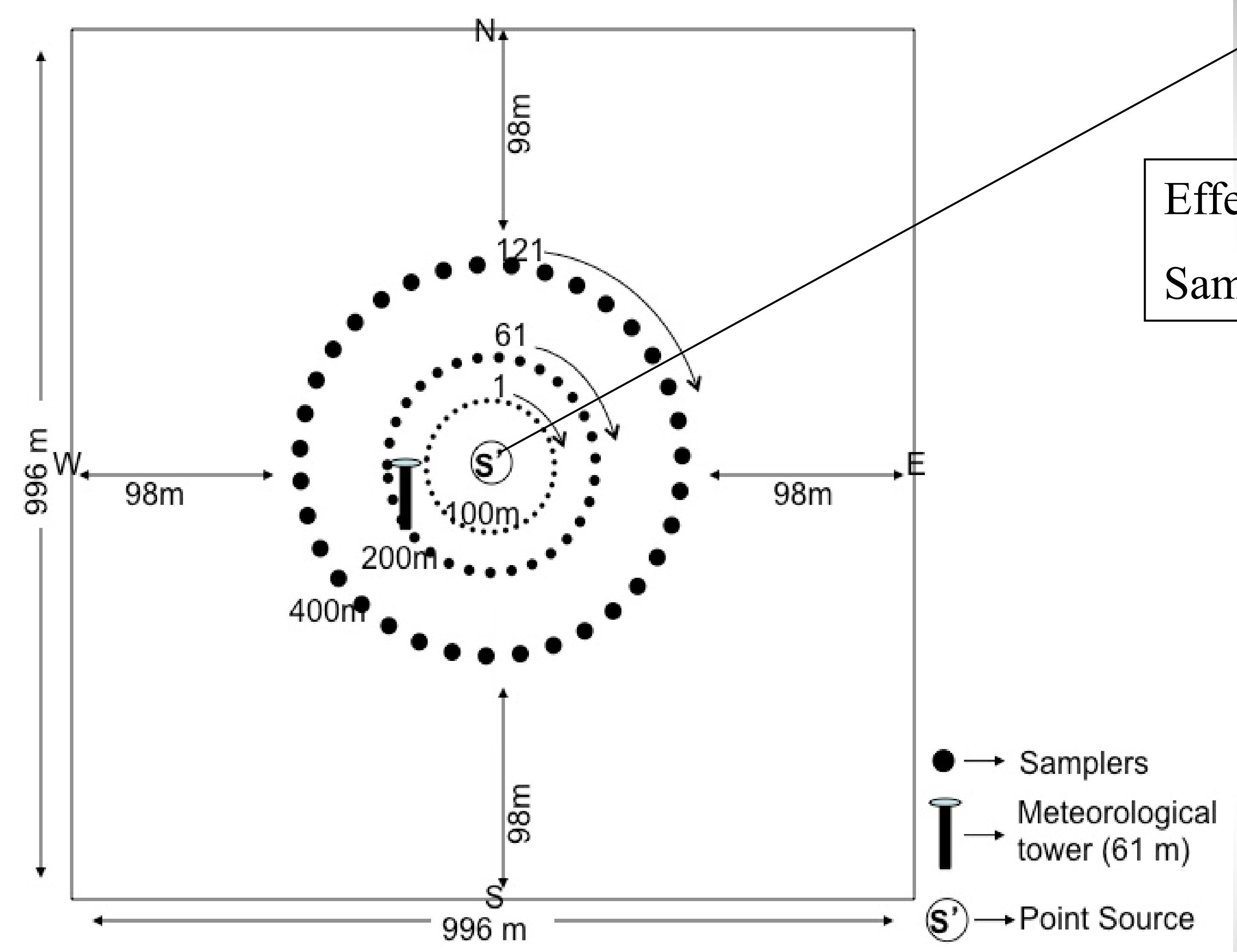
Using cauchy-schwarz inequality, $|s_0(\mathbf{x})| \leq 1$

Maximum of the $s_{\|\varphi}$ coincides with the point source **location**.

Now, ***intensity*** *can be computed as,*

$$\boxed{\widehat{q} = \frac{s_{\|\varphi}(\mathbf{x}_0)}{\varphi(\mathbf{x}_0)}}$$

IDAHO Diffusion Experiment



Source lies at grid point (250, 250, 31).

Effective Release Height = 3m

Sampling Height = 0.76m

Each mesh is a box of 2m×2m×0.1m.

In run# 4, the release was 32000μg/sec

Computation

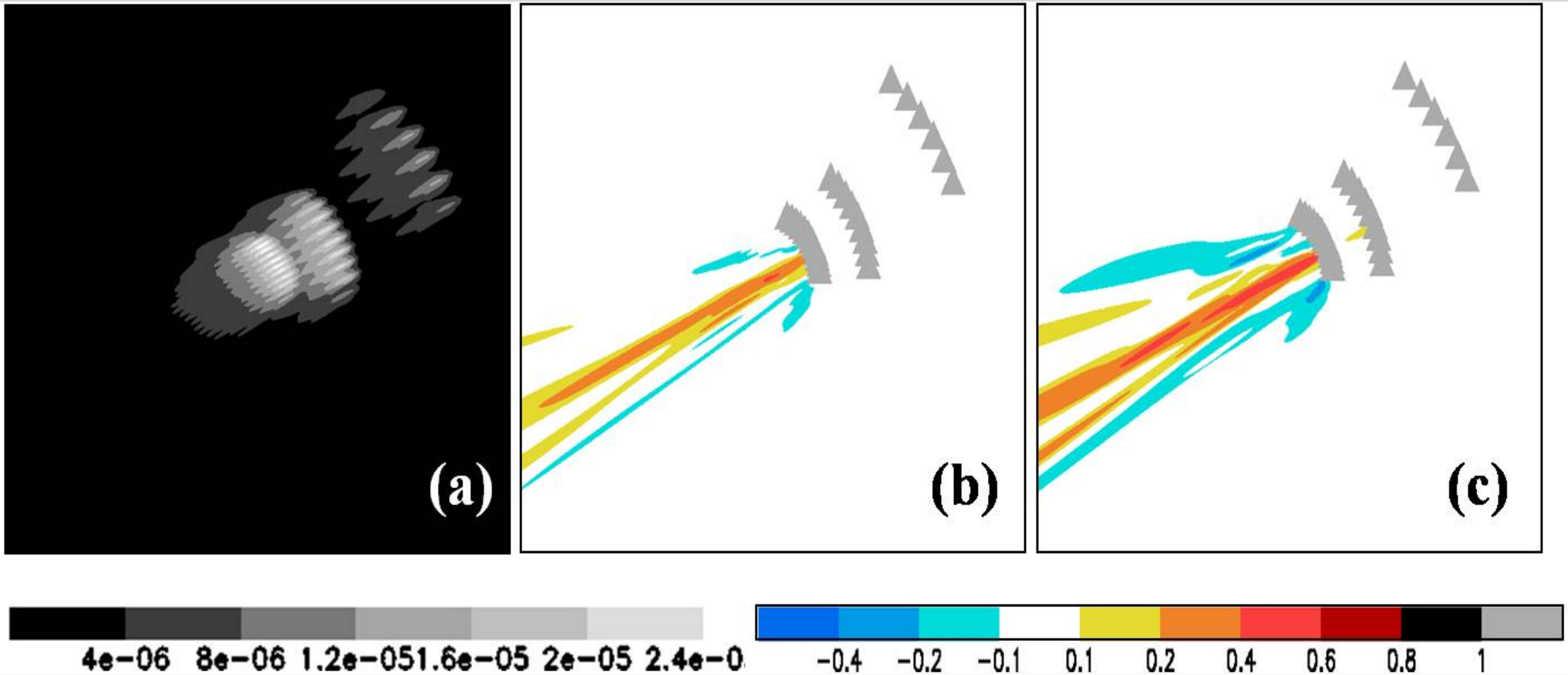
- Analytical Dispersion Model: Sharan et al.(1996)
- Dispersion parameterization:
  - In horizontal direction : Luhar (2011)
  - In vertical direction : Briggs (1973)
- Plume is segmented in to 30 sub-intervals

Evaluation

- Synthetic data
- Real data

	Release Parameters			$s_{\|\varphi}$		φ at ($\times 10^{-6}$)	
	(x_0, y_0, z_0)	h	q	Real	Est.	Real	Est.
Experimental	(250, 250, 31)	3	32000	-	-	-	-
Reconstruction with Synthetic data	(250, 250, 31)	3	32000	1.02	1.02	31.9	31.9
Reconstruction with Real data	(253, 254, 31)	3	39156	1.36	1.42	31.9	36.3

Figures



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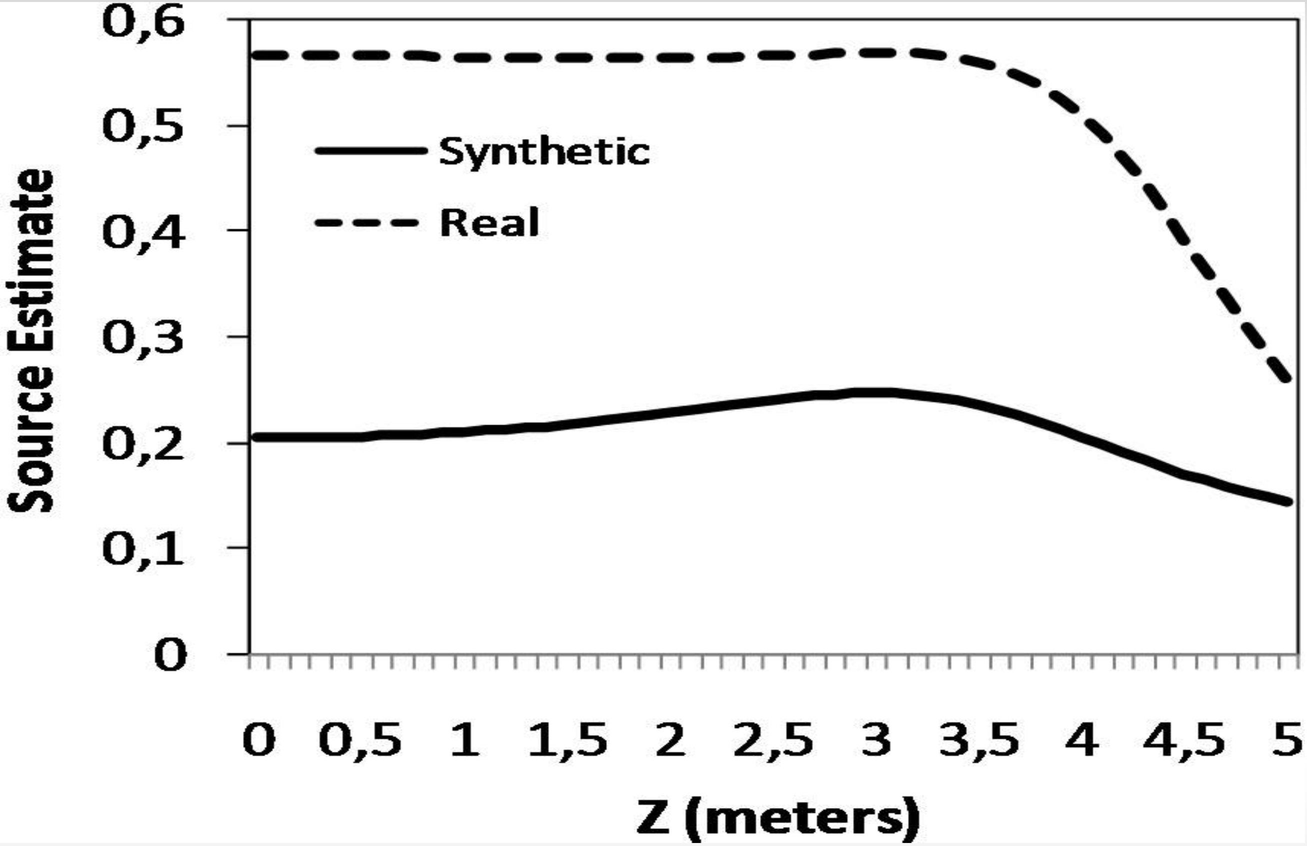
0,6
0,5
0,4
0,3
0,2
0,1
0
Source Estimate
Synthetic
Real
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Z (meters)

Conclusions

- Propose a new method of source retrieval.
- Free from any prior information regarding release or its background state.
- Singularities due to point measurements can be dealt in a natural manner.
- Utilize the information from geometry of the monitoring network.
- With Idaho data, the Release is identified within a distance of 10m with 22% over-estimation of emission rate.

Thanks for your Kind Attention

Articles

- Issartel, J.-P., M. Sharan and M. Modani, 2007: An inversion technique to retrieve the source of a tracer with an application to synthetic satellite measurements. *Proc. Roy. Soc. A*, **463**, 2863-2886.
- Sagendorf, J. F. and C. R. Dickson, 1974: Diffusion under low wind speed inversion conditions. *NOAA Technical Memo-ERL-ARL-52, Air Resources Laboratories, Silver Spring.*
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- Luhar AK. 2011: Analytical puff modelling of light-wind dispersion in stable and unstable conditions. *Atmos. Environ.* **45,** 357–368.
- Singh, S.K., Sharan, M. and Issartel, J.P.: (2013), ‘Inverse Modelling for Identification of Multiple-Point Releases from Atmospheric Concentration Measurements’. *Boundary-Layer Meteorol.*, **146**, 277-295.

Invitation to Workshop

Atmospheric Modeling

"Dispersion, Source Identification, Air Quality"

Organized at

LMEE, University d'Evry, Evry (near Paris), France

On

Monday, 10th June 2013 (9:30 -16:30)

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