Source estimation using fixed, moving and remote concentration and airflow measurements, and kinematic simulation

Forum on
Source Term Estimation and Event Reconstruction,
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Typical Scenarios/Applications

1. Source detection (e.g. oil refinery), 100m–1km.
   • useful for regulation.

2. Near source (e.g. security problems), 10–100m.
   • note new instrumentation available for remote detection of concentrations and temperature, wind and turbulence;
   • faster computers, but fast algorithms still needed.
Detecting Sources – by fixed, moving and remote measurements

1. **Standard algorithms for forward dispersion:**

   \[ C(x, t) = \sum Q_n f(x - s_n, t - t_n) \]

   - Here \( C \) is the concentration at \( x \), at time \( t \), \( Q_n, s_n, t_n \) are source strength, location and release time of \( n^{th} \) source
     - Statistical models are used to predict \( \bar{C}, C' \) and other moments
     - Stochastic modes of \( s \) and \( u \), predict real time structure

2. **Backward or upwind dispersion:**

   - Given \( C(x_m, t_p) \) at measurement points \( x_m \), measurement times \( t_p \), find source parameters \( Q_n, s_n, t_n \)

   - Note if different species are measured (e.g. Sulphur, CO), consider as different sources.

   - Methodology is to define local source(s), \( s_n \), using measurements of the indicative *structure* of the concentration distributions
Temperature traces and temperature frequency distributions on the plume centreline downwind of a line source at two locations downstream— from *Stapountzis et al (1986)*

Similar data from field – non-Gaussian near source – sharp fluctuations.
Typical concentration space–time profiles

- Wind direction variations
- Location of measuring point
- Actual plumes
- Estimate of plume (iteration i, realisation R)
- Cross-section path by observer
- Profile
- Filtered signals (maximum)
- Variation at a point
- C(x_m, t)
- C(y)
- R = 1
- R = 2
- Δy ~ σ_y
- Δt ~ σ_t
Detection of sources on boundary layer length/time scales

1. From inspection of plumes (e.g. detect maxima $\hat{C}_r, r = 1, 2, 3...$) derive plume scales $\Delta t \sim \frac{X}{u'}; \Delta y \sim \frac{X u'}{U}$ leads to $X^i(t)$; an $i^{th}$ estimate of distance from measurement to each source.

2. Statistical quantities derived from measurements

<table>
<thead>
<tr>
<th>y profile</th>
<th>$\tilde{Y}_y^{(R)}$, $\tilde{Y}_r^{(R)}$, $\hat{C}_r^{(R)} \Rightarrow S_r^{(i,R)}, Q_r$</th>
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<tbody>
<tr>
<td>or t profile</td>
<td>$\tilde{Y}_t^{(R)}$, $\hat{t}_r^{(R)}$, $\hat{C}_r^{(R)} \Rightarrow S_t^{(i,R)}, Q_r$</td>
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Sources for iteration $i$ (realisation $R$, $r^{th}$ source)

3. Then calculate forwards, from sources located at $X_r^{(i,R)}$ for each realisation of measurements. This leads to first approximation, plus error.

4. Improve estimates and errors, by simulating ensembles of mean and fluctuating wind field (Kinematic Simulation), and then compute concentration, using simulated velocity fields, $u(x,t)$. 
Detection of sources on smaller surface layer scales

Short distance; single small source – as before, location and strength is unknown.

Profile $C(y, t)$, e.g. by moving vehicle
Detector at $x_m$ to detect likely sources

The fact that the wind direction is changing provides key information about the source.
Complex problems

(i) Consider isolated buildings (these are visible)

Detection concept – if $\hat{\sigma}_{yR}$ is small for $R=1$

is large for $R=2$

then likely that source is near building.

Then iterations of forward diffusion for $s^{(i)}$ should allow for

building. [cf studies by Davidson et al.]

(ii) Canyons/streets

Time series data recorded in a building array plume and control plume (no buildings). From Davidson et al 1993.
Conclusion

1. Totally general methods of source estimation are not practical as with forward/downwind dispersion (use flow/source dependent fast/simple model).

2. Less concentration sampling is needed if there is some information about sources (localised; distributed) and whether sources are located near hills, obstacles or street canyons.

3. Accuracy, and thus type of model used, depends on:
   i. Information about wind field between source and receptor
   ii. Spatial extent, length of time (or numbers of samples) and resolution of sampling.
   iii. Length of period for analysis – may be limited for security problems. But if longer time is available, more analysis is useful (e.g. filtering, cross correlation analysis)