# CB Weapon Environment Prediction: Source Term Estimation

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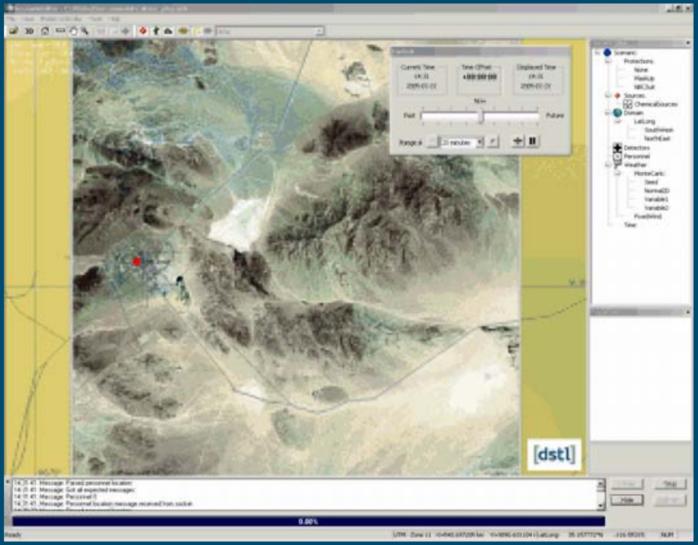
# Operational Need



- Operational strategy: base CBRN Hazard Estimates on dispersion models.
- Dispersion modelling is dependent on Source Term parameters
- For covert CBR releases, Source Terms will not be known
- Fast source term estimation needs to be performed
- An estimate of the uncertainty of the Source Term aids decision making

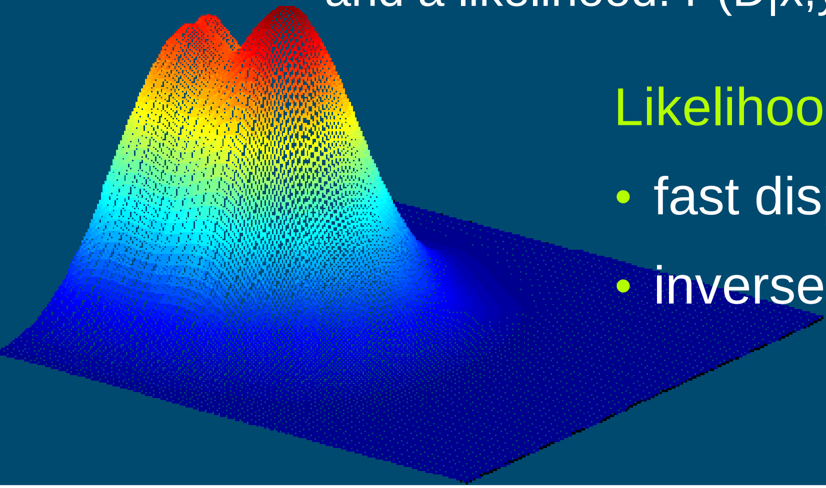
# Introduction

## Bayesian approach

- P(D|H) is generally intractable, instead we calculate relative probabilities
- to calculate probabilities of hypotheses P(x,y,Q,t,A|D), we need:
  - a prior: P(x,y,Q,t,A)
    - and a likelihood: P(D|x,y,Q,t,A)

$$P(H \mid \mathbf{D}) = \frac{P(\mathbf{D} \mid H)\,P(H)}{\sum_{H} P(\mathbf{D} \mid H)}$$

$$\frac{P(H_A \mid \mathbf{D})}{P(H_B \mid \mathbf{D})} = \frac{P(\mathbf{D} \mid H_A)\,P(H_A)}{P(\mathbf{D} \mid H_B)\,P(H_B)}$$

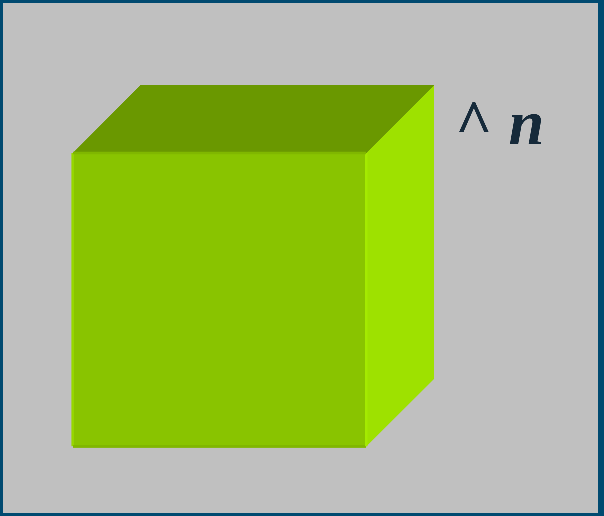


## Likelihood calculation needs either:

- fast dispersion model
- inverse dispersion run

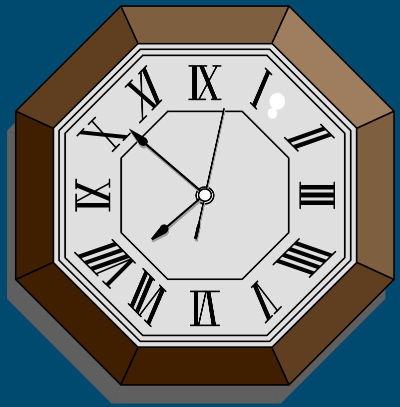
# Technical Problems

- multidimensional search space;
  - sampling strategies to make efficient hypotheses in hypercube
- computational efficiency
- fixed / mobile sensors
- fusion of disparate data
- modelling sensor response
- biological source term estimation
- Evaluation of methodology



# Technical Problems

- multidimensional search space;
- computational efficiency
  - target: source term estimation 5 minutes after first detection
- fixed / mobile sensors
- fusion of disparate data
- modelling sensor response
- biological source term estimation
- Evaluation of methodology

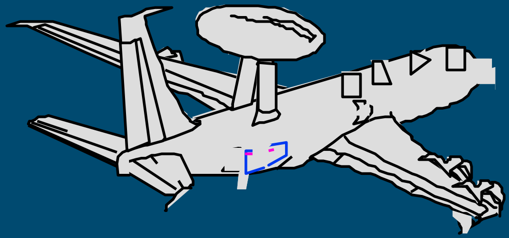


# Technical Problems


- multidimensional search space;
- computational efficiency
- fixed / mobile sensors
  - fixed sensors → high data rate.      Mobile sensors → position unknown
- fusion of disparate data
- modelling sensor response
- biological source term estimation
- Evaluation of methodology

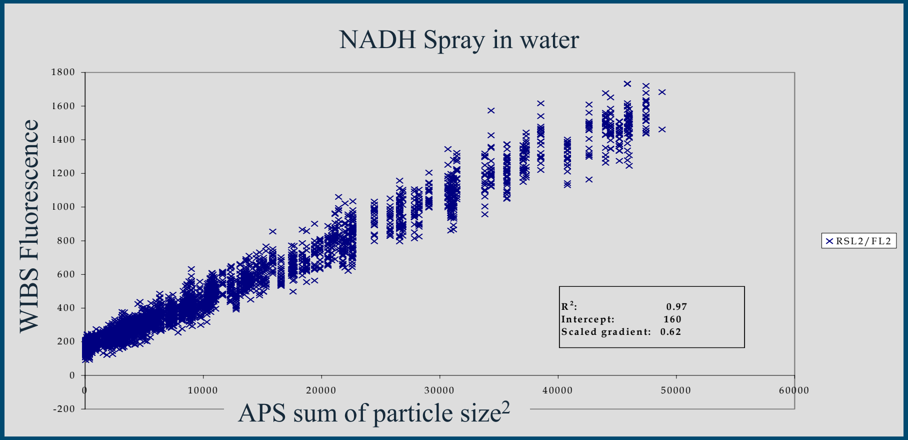
# Technical Problems

- multidimensional search space;
- computational efficiency
- fixed / mobile sensors
- fusion of disparate data
  - e.g. human observations, ISTAR observations
- modelling sensor response
- biological source term estimation
- Evaluation of methodology



# Technical Problems

- multidimensional search space;
- computational efficiency
- fixed / mobile sensors
- fusion of disparate data
- modelling sensor response
  - so that sensor uncertainty can be accounted for
- biological source term estimation
- Evaluation of methodology



# Technical Problems

- multidimensional search space;
- computational efficiency
- fixed / mobile sensors
- fusion of disparate data
- modelling sensor response
- biological source term estimation
  - biological background leads to false alarms
- Evaluation of methodology

# Technical Problems

- multidimensional search space;
- computational efficiency
- fixed / mobile sensors
- fusion of disparate data
- modelling sensor response
- biological source term estimation
- Evaluation of methodology
  - objective validation

# Multidimensional Search Space

- Differential Evolution - Markov Chain
- On start-up several hypotheses, (we use 50) are distributed throughout the prior, these form the start of Markov Chains
- For each hypothesis, run the UDM to calculate the parameters of the clipped Gaussian ($\mu$,$\sigma$)
- Then the probability/ weighting of each hypothesis can be calculated immediately data becomes available
- During ideal time, cycle through each Markov Chain in turn. New jumps are proposed from difference between chains

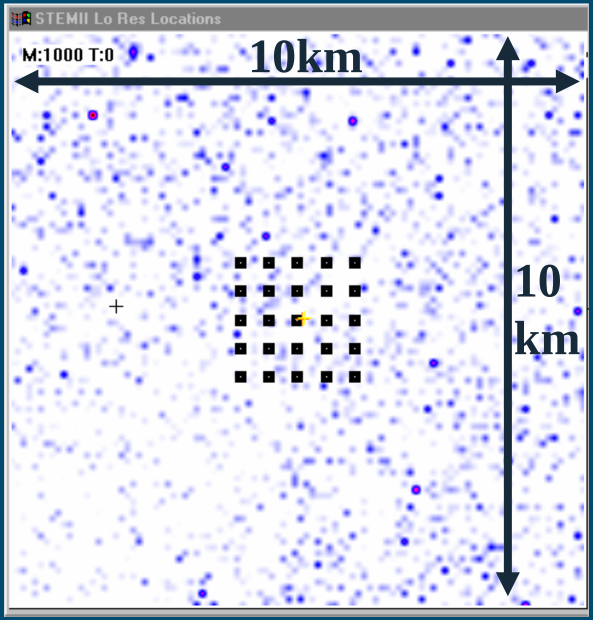
$$\mathbf{x}_{i,new} = \mathbf{x}_{i,old} + \gamma\left(\mathbf{x}_j - \mathbf{x}_k\right) + \varepsilon, \quad i \neq j \neq k$$

- Adaptive: Population mimics distribution (inc. correlations).
- Aggressive expansion from degeneracy.

# Computational Efficiency

## Idle time processing

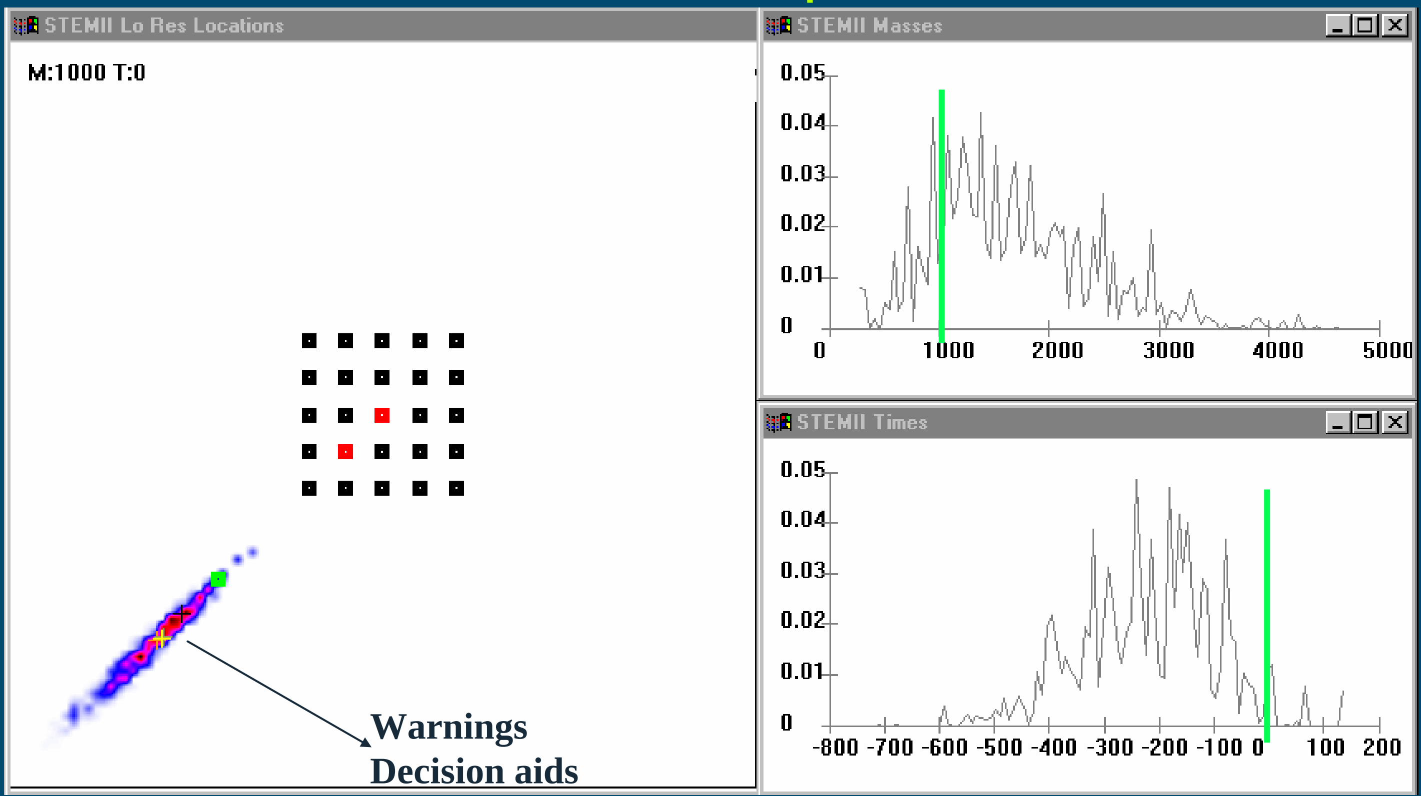
- Add new samples to map out posterior according to current data.
  - Propose new samples.
    - Differential Evolution – Markov Chain.
  - Two-Step Accept/reject.
- Check for data.
- Sample Importance Resample if:
  - Few hypotheses have significant weight.
  - Data process time rules out idle time.



# Computational Efficiency

Chem scenario, fixed sensors

5 minutes after first sensor responds



# Fixed / mobile sensors

- Fusion of data from mobile sensors

- Previously unreported sensors, e.g. with a manoeuvre unit
- No opportunity to perform pre-processing
- Alarm only (rather than bar reading or concentration)

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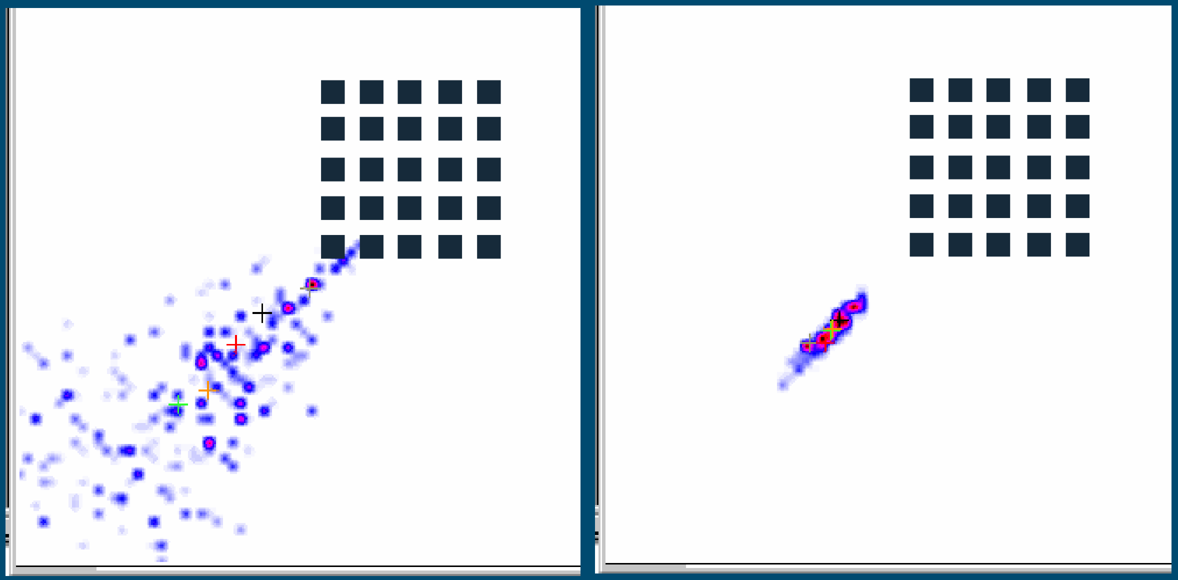
**Solution:**

- **Dispersion model adjoint**
- **Current simplifying assumptions include spatially homogeneous wind flow and terrain - in this case, the reversal of wind and time form an exact adjoint**

# Human observations

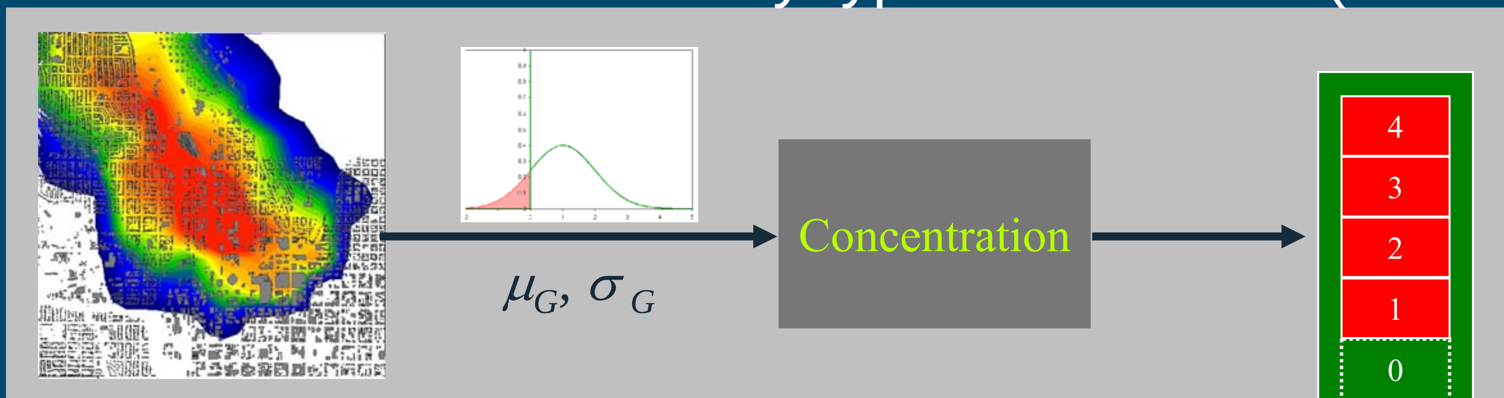
- Human observation fusion
  - Either bearing-only or bearing and range



- **Bearing uncertainty modelled as Gaussian**
- **Range uncertainty modelled as Log-normal**

# Sensor response models

- Probabilistic models of sensor response
  - Chemical sensor: Ion Mobility type “bar” sensor (≡ACADA)




  - model P(bar|dispersion code output).

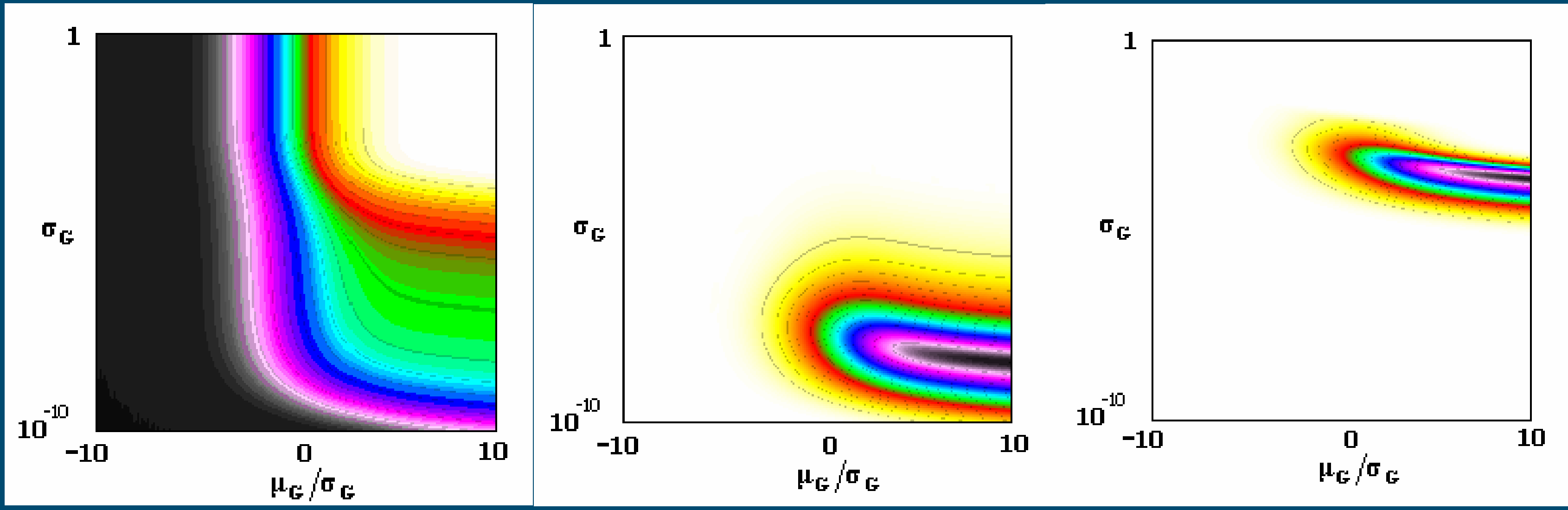
$$P\left(bar_i \mid \mu_G, \sigma_G\right) = \int_0^{\infty} P\left(bar_i \mid c\right) P\left(c \mid \mu_G, \sigma_G\right) dc$$

$$P\left(bar_i \mid \mu_N, \sigma_N^2\right) = \int_0^{\infty} \frac{1}{\sqrt{2\pi(\alpha c + J)}} \int_{T_{i-1}}^{T_i} e^{-\frac{1}{2}\frac{(V-c)^2}{(\alpha c + J)}} dV \left[ \frac{1}{2}\left(1 - \operatorname{erf}\left(\frac{\mu_N}{\sigma_N \sqrt{2}}\right)\right) \delta(c) + \frac{1}{\sigma_N \sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{c-\mu_N}{\sigma_N}\right)^2} \right] dc$$

# Sensor response models

- Probabilistic models of sensor response

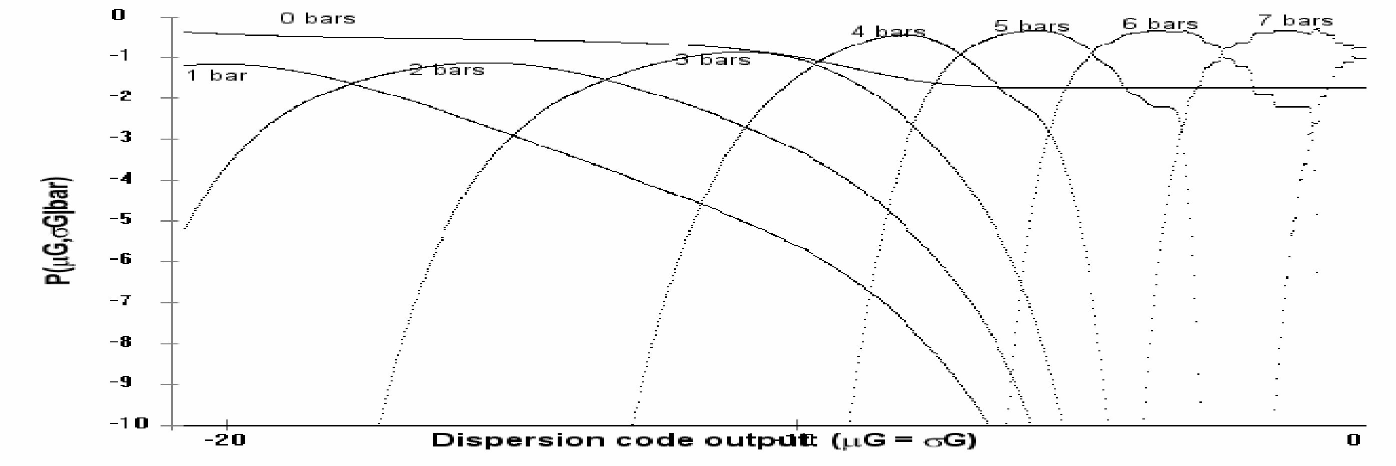
  - Look-up table of pre-computed integrals

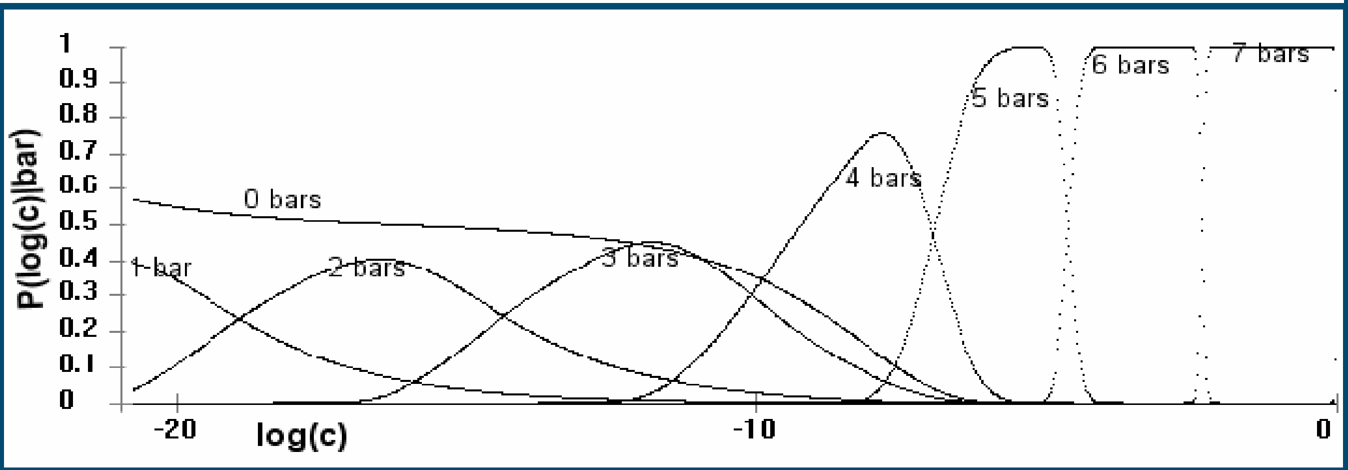



**0 bars** **1 bar** **4 bars**

# Sensor response models

- Probabilistic models of sensor response



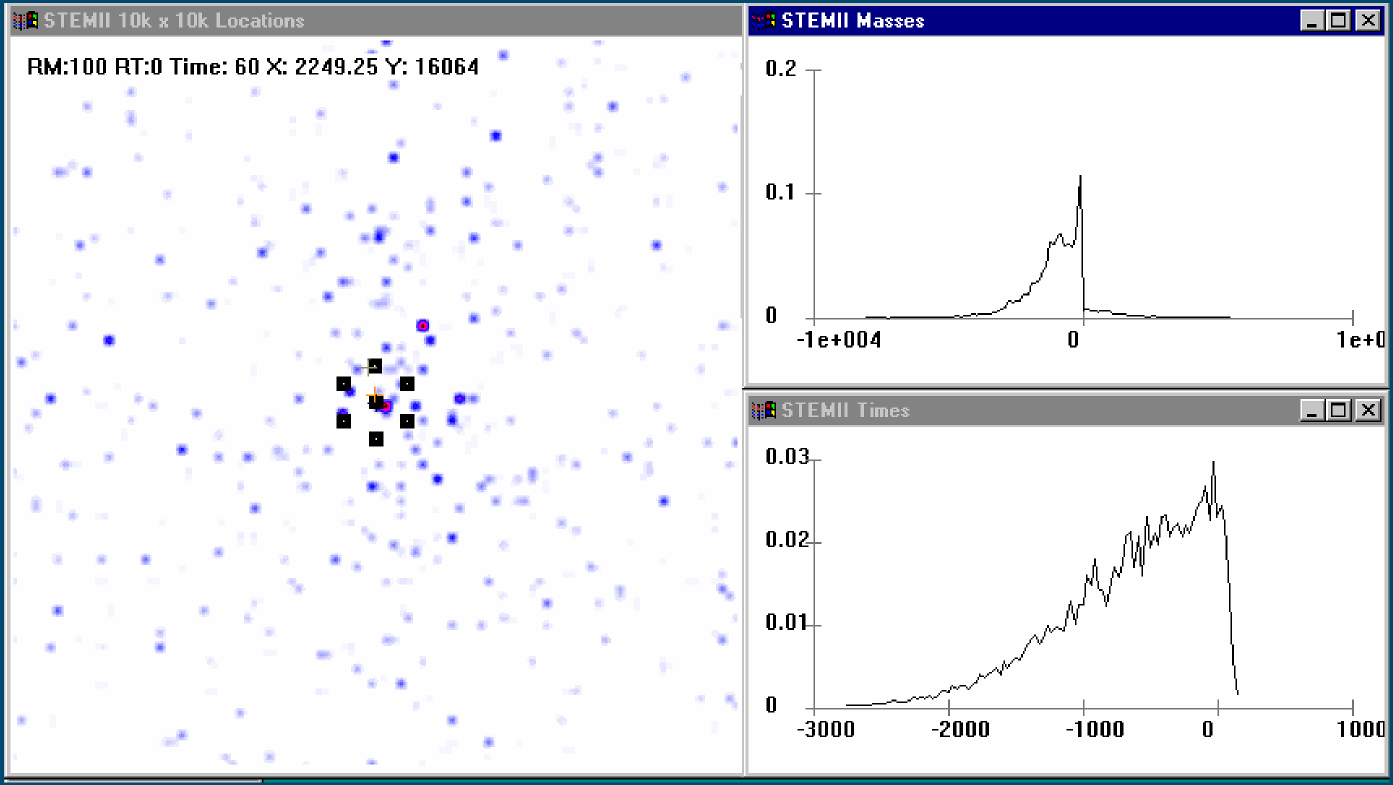



# Source Term Estimation video

## Chemical scenario

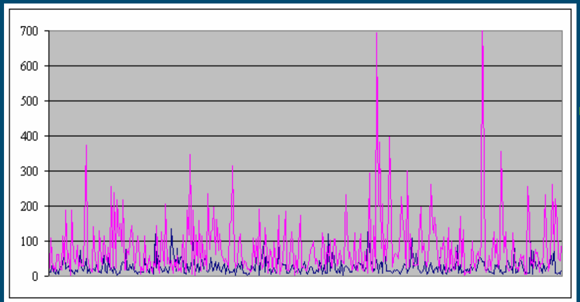
(faster than real time 1s = 1m)

- Actual releases:
  - Mass 100kg.
  - Time 0s.
  - 7 x bar detectors



# Biological sensor fusion

- Biological background




Real background

Exponentially weighted moving av. of Poisson distributed background

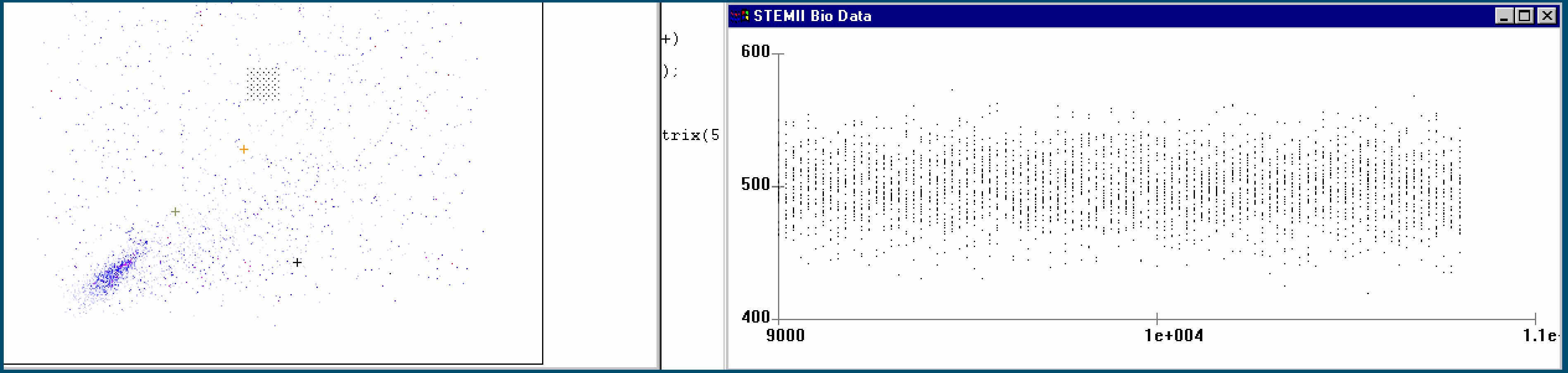
$$\mu_t = \alpha\mu_{t-1} + (1-\alpha)s_{t-1}\ .$$

i.e. mean = variance

STEM's internal model of background

Source Term Estimation

bkgrd subtracted sensor reading




Video of EWMA background discrimination (inc. simplistic background model)

# Biological sensor fusion

- Biological sensor model

Simple particle counter sensor

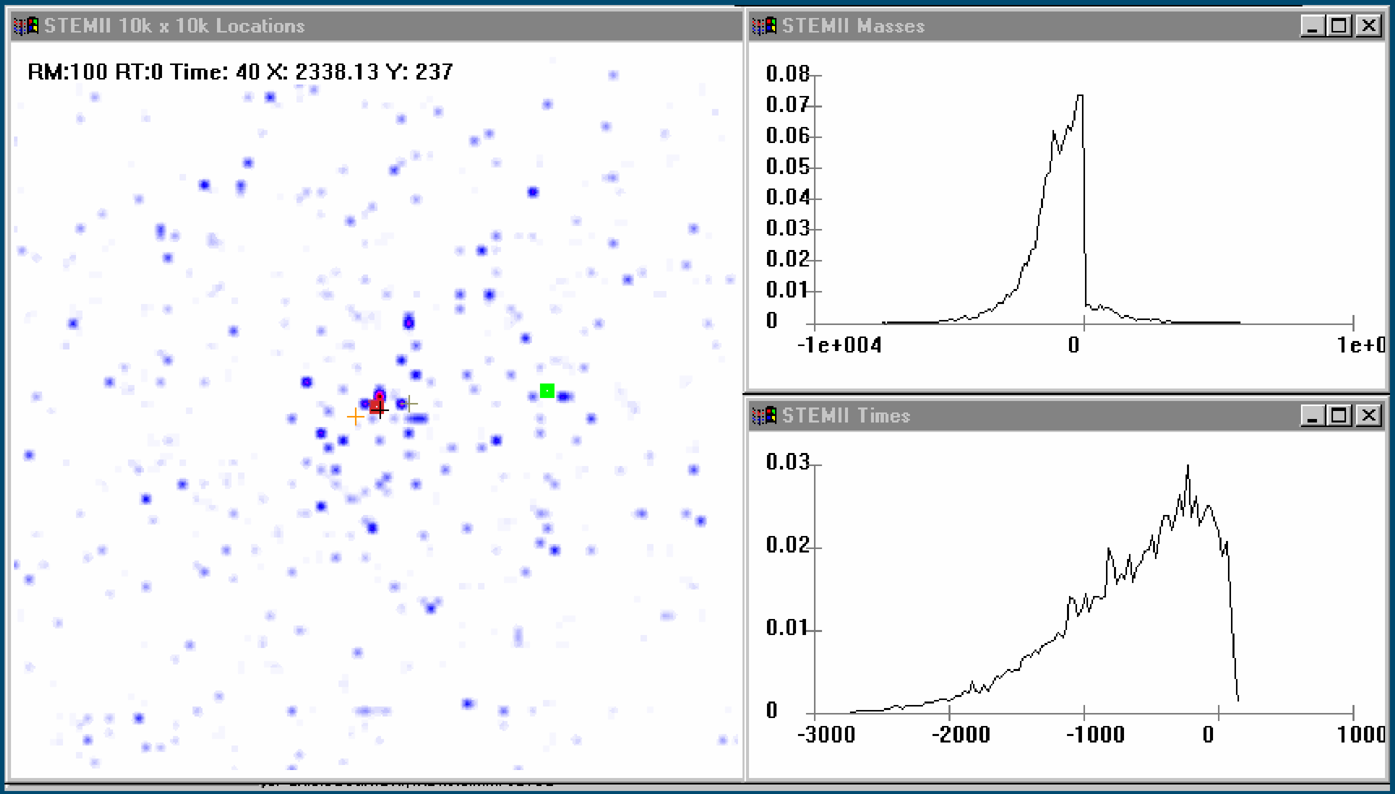

Immuno-Assay detector

# Source Term Estimation video

Biological scenario

(faster than real time 1s = 1m)

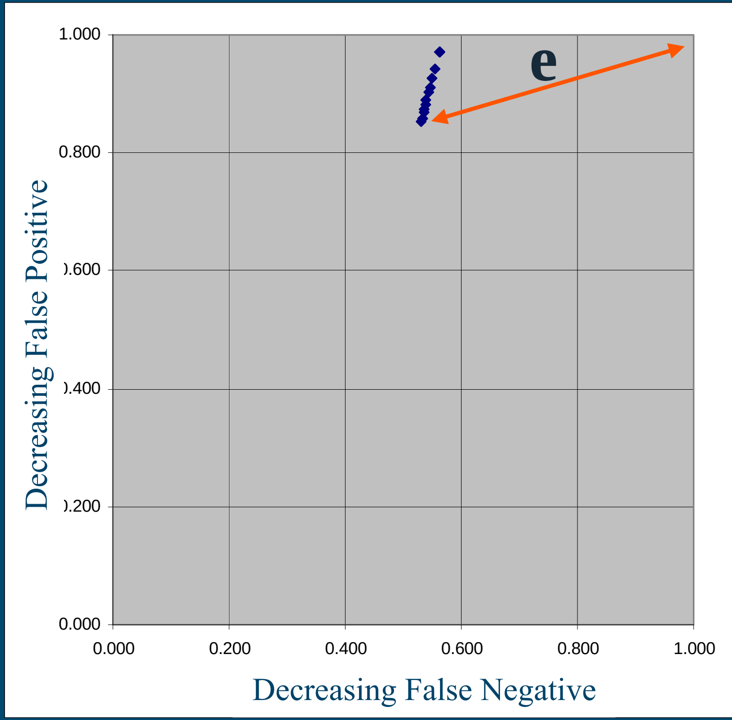
- Actual releases:
  - Mass 100kg.
  - Time 0s.
  - 1 x particle counter

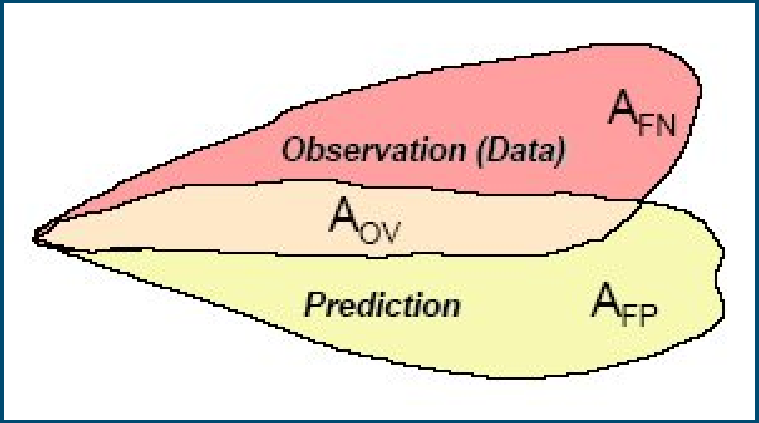


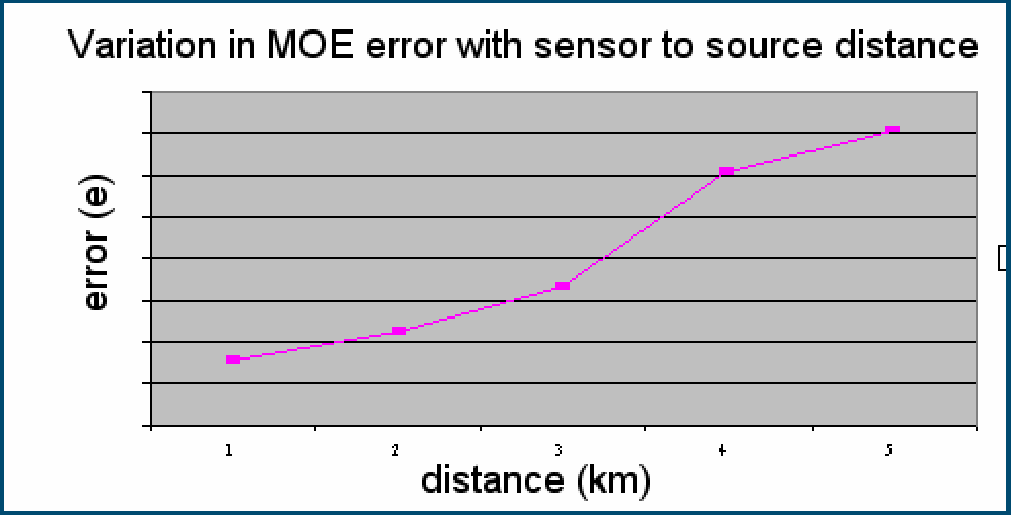
# Evaluation of methodology

- Evaluation system built

- Measure of effectiveness – compares the areas of overlap, over and under-prediction between an the observed and predicted.



# Peer Review

- Two papers presented at Fusion 2005 conference
- (Philadelphia, USA. July 25 - 29, 2005)

- **“Non-Linear Bayesian CBRN Source Term Estimation”.** Peter Robins and Paul Thomas

- **“A Probabilistic Chemical Sensor Model for Data Fusion”.** Peter Robins , Veronica Rapley and Paul Thomas

# Future Research FY05 & FY06

- Extensive evaluation of STEM II will be carried out to determine performance in a synthetic environment
- More probabilistic models of sensor response will be built
- Extending the techniques developed for chemical releases to work for biological releases, in the presence of the natural background.
- Research will be carried out in order to speed up some of the more difficult mathematical calculations to make the system suitable for operational use in complex terrain and urban areas.
- Research will be carried out to allow modelling of multiple source terms and line strikes.

# Questions?