Source Estimation from Sensor Alarms using SCIPUFF

R. I. Sykes and B. Chowdhury
Titan Research & Technology Div., Titan Corp.
50 Washington Road
Princeton NJ

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Research Objective

- Use “realistic” sensor alarm information to estimate source characteristics using probabilistic SCIPUFF prediction
  - time, location, mass
- Develop a quantitative “likelihood” measure to compare prediction with sensor output
  - use measure in conjunction with multiple predictions to “maximize” likelihood
- Work sponsored by Oak Ridge National Laboratory (ORNL) as part of the SensorNet program

Idealized Sensor Model

- Typical sensor alarm has a binary output, i.e., alarm is ON or OFF
- Simplified model is based on a response time, τ_s, and an alarm level, c_a
- Given concentration time series, $c(t)$
  - determine sensor response, s, in specified time period as

$$s = \begin{cases} 1, & c_s > c_a \\ 0, & \text{otherwise} \end{cases} \quad \text{where} \quad \frac{d\,c_s}{d\,t} = \frac{c - c_s}{\tau_s}$$

Probability of Alarm

- SCIPUFF predicts a probabilistic concentration, c
- Determine mean response

$$\overline{s} = \text{Prob}\left(s = 1\right) = \text{Prob}\left(c_s^{(\max)} > c_a\right)$$

- Variance of predicted response is simply

$$\sigma_s^2 = \overline{s}\left(1 - \overline{s}\right)$$

A Likelihood Measure

- A commonly used statistical measure for comparing a set of predictions with observations is

$$L = \left(s_i^{(obs)} - \overline{s}_i \right) V_{ij}^{-1} \left(s_j^{(obs)} - \overline{s}_j \right)$$

- where $V_{ij} = \overline{s_i' \, s_j'}$
- i.e. difference is weighted by inverse of predicted variance - diagonal elements
- Note that full matrix requires two-point correlations (both space and time, in general)

Joint Probability

- Correlation estimate requires joint probability:

$$\overline{s_i' s_j'} = \overline{s_i s_j} - \overline{s_i}\,\overline{s}$$

$$= \mathrm{Prob}\left(s_i = 1 \;\&\; s_j = 1\right) - \overline{s_i}\,\overline{s}$$

- Estimate from numerical integration of 2-D truncated Gaussian for (c_i, c_j), with correlation ρ_{ij}

- Note that predicted variances are reduced due to "averaging" over response time, τ_s

Concentration Correlation

- Correlation ρ_{ij} is based on separation in space and time relative to predicted correlation scales

$$\rho_{ij} = \exp\left(-\sqrt{\frac{\Delta s^2}{\ell_s^2} + \frac{\Delta t^2}{\tau_L^2} + \frac{\Delta y^2}{\ell_y^2}} \right)$$

- where Lagrangian streamwise separation is

$$\Delta s = \left(\Delta \boldsymbol{x} - \boldsymbol{u} \Delta t \right) \cdot \frac{\boldsymbol{u}}{|\boldsymbol{u}|}$$

- and Δy is cross-stream separation

A Practical Problem

- The predicted variance, σ_s, can be zero when the probability of alarm is zero or unity - implies infinite L
- Apply limit in current work, so that $\sigma_s^2 > 0.1$
- Note that finite probability of false alarm or failure to alarm will eliminate the singularity

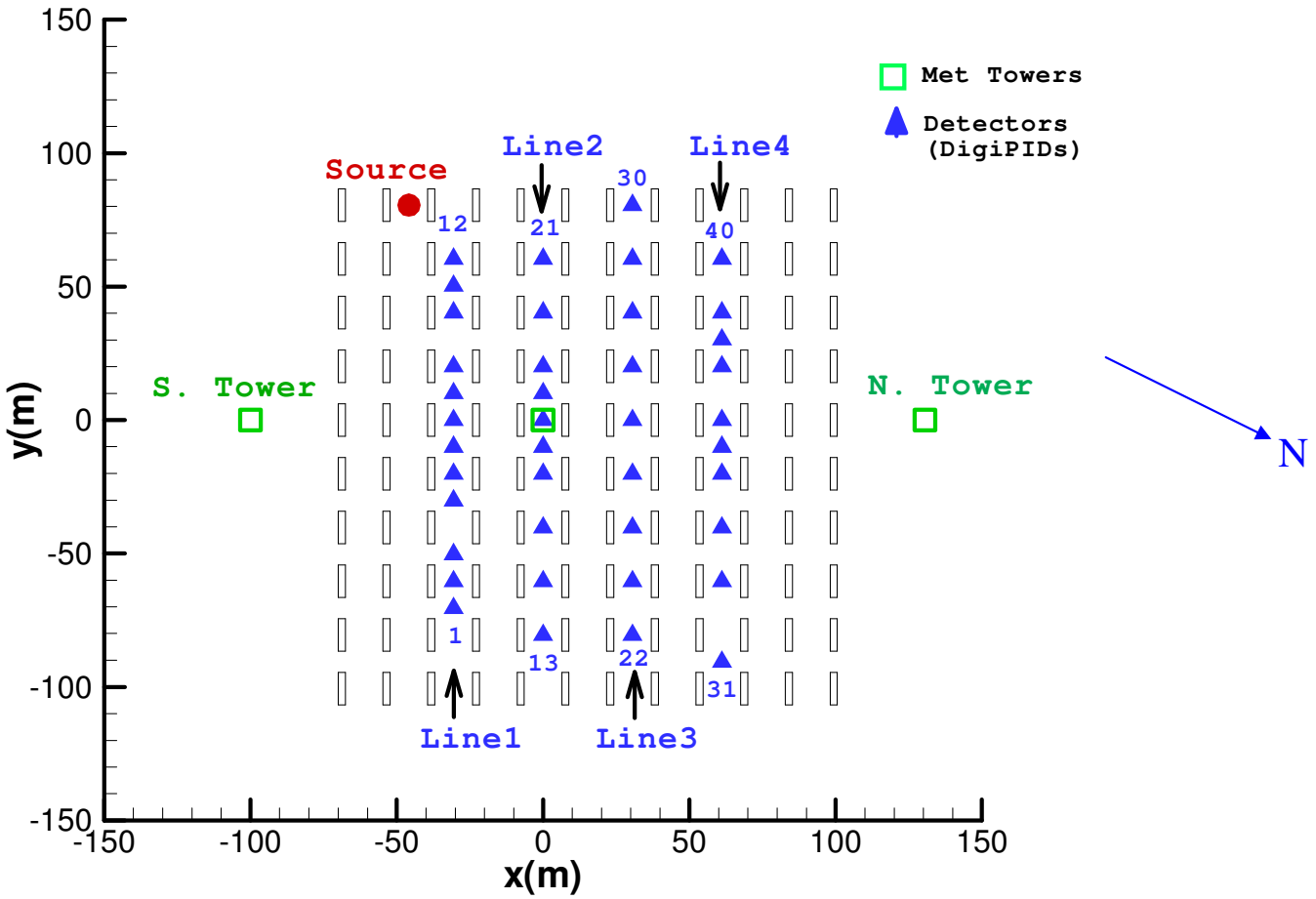
$$\overline{s} = (1-p)\,q_{false} + p\left(1-q_{fail}\right)$$

so cannot be zero if q's are non-zero

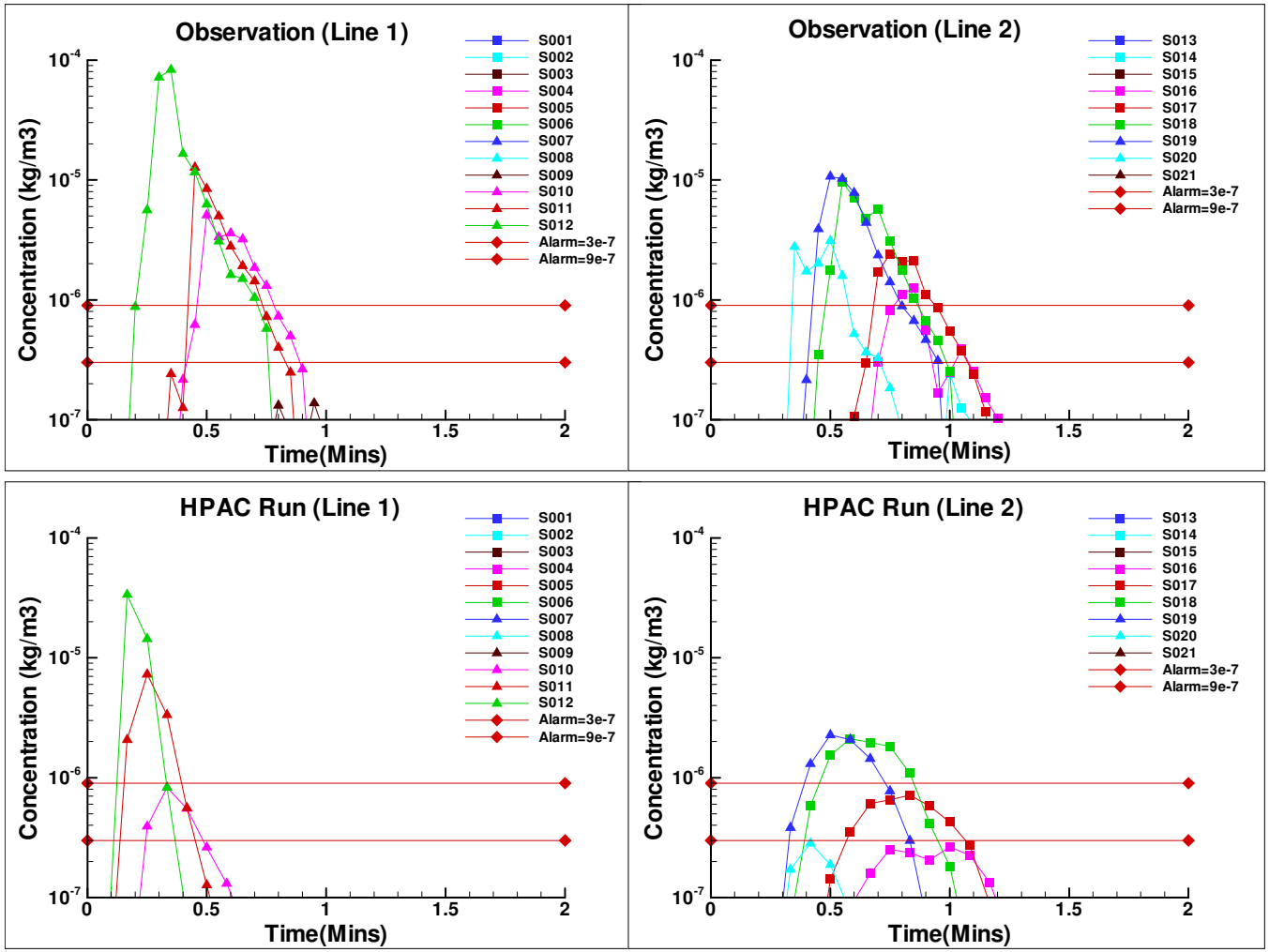
Sample Application - MUST

- Mock Urban Setting Test trials at Dugway
- 48 Digital Photo Ionization Detectors
- Use one of the puff releases
- Alarm response time 3s, repeat interval 5s
- Examine location likelihood sensitivity to
  - release mass
  - release time
  - alarm level
  - turbulence / uncertainty assumption

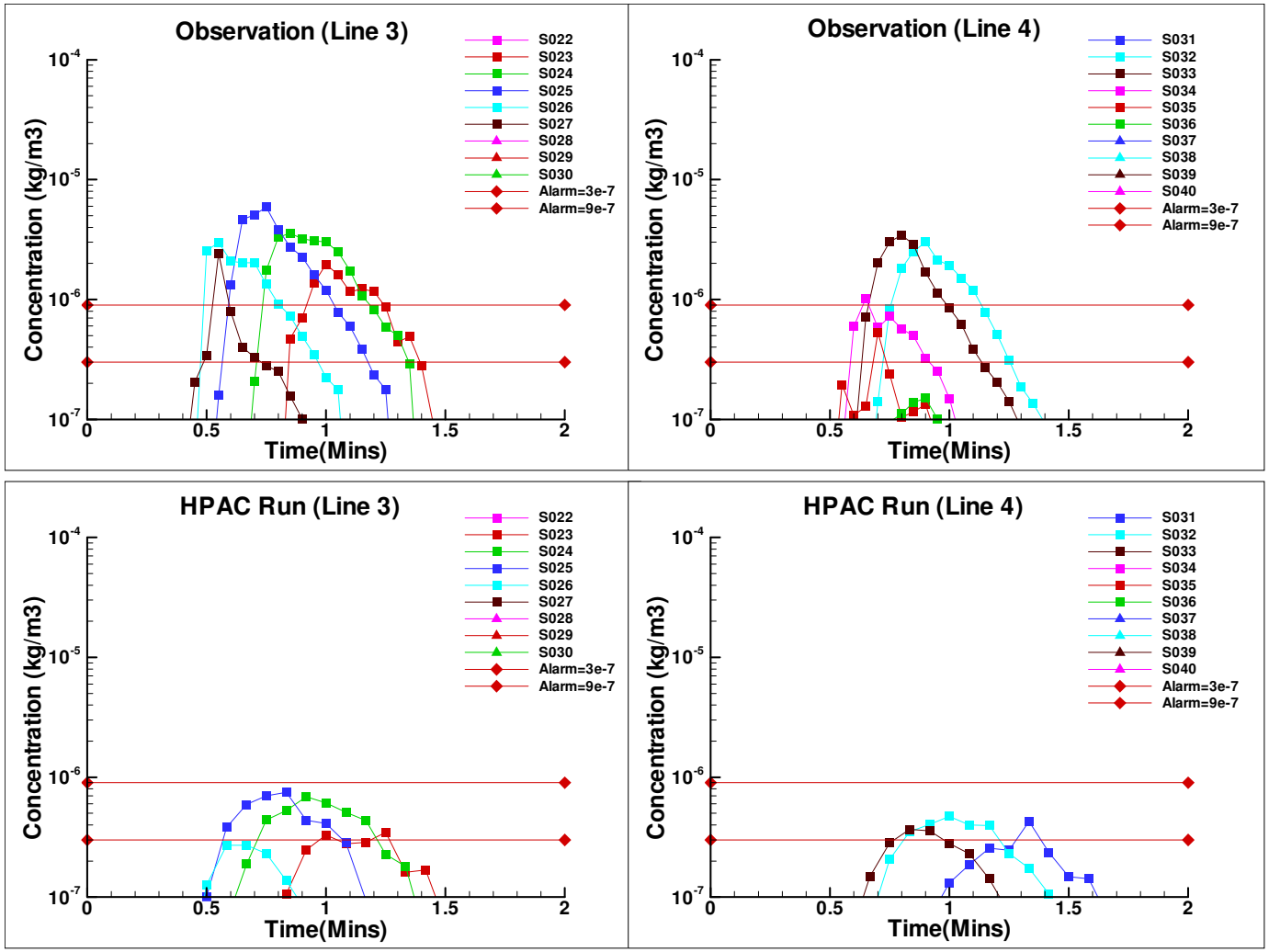
MUST Setup – Nominal Geometry



Concentration plots (Line 1 & 2)



Concentration plots (Line 3 & 4)

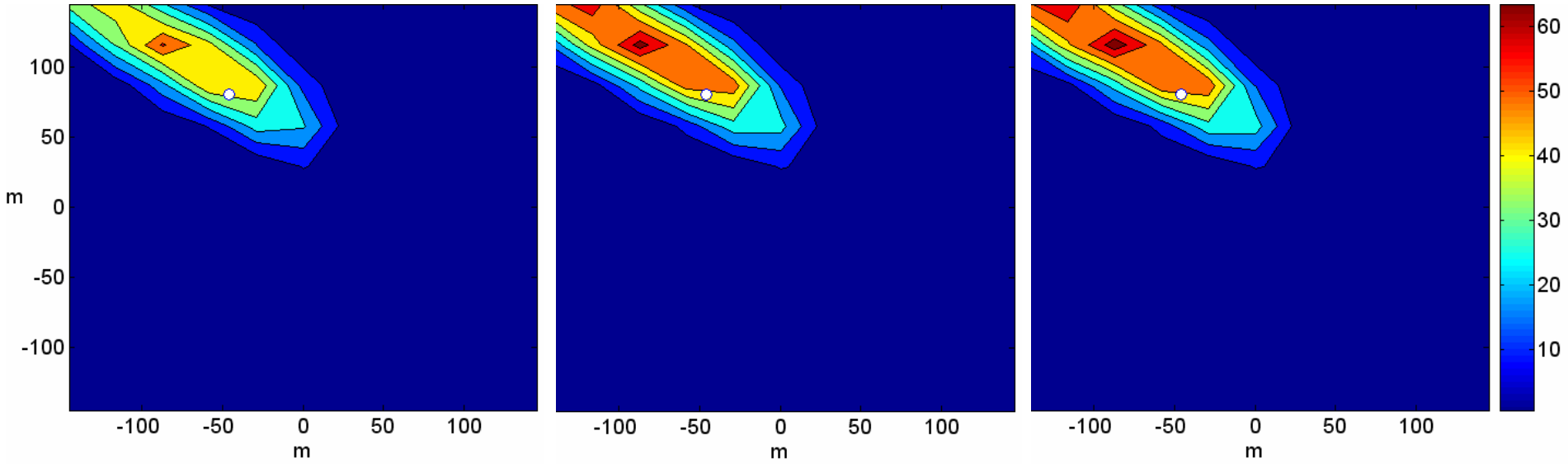


Likelihood Plots (Mass Ratio)

Mass Ratio = 1

Mass Ratio = 3

Mass Ratio = 9

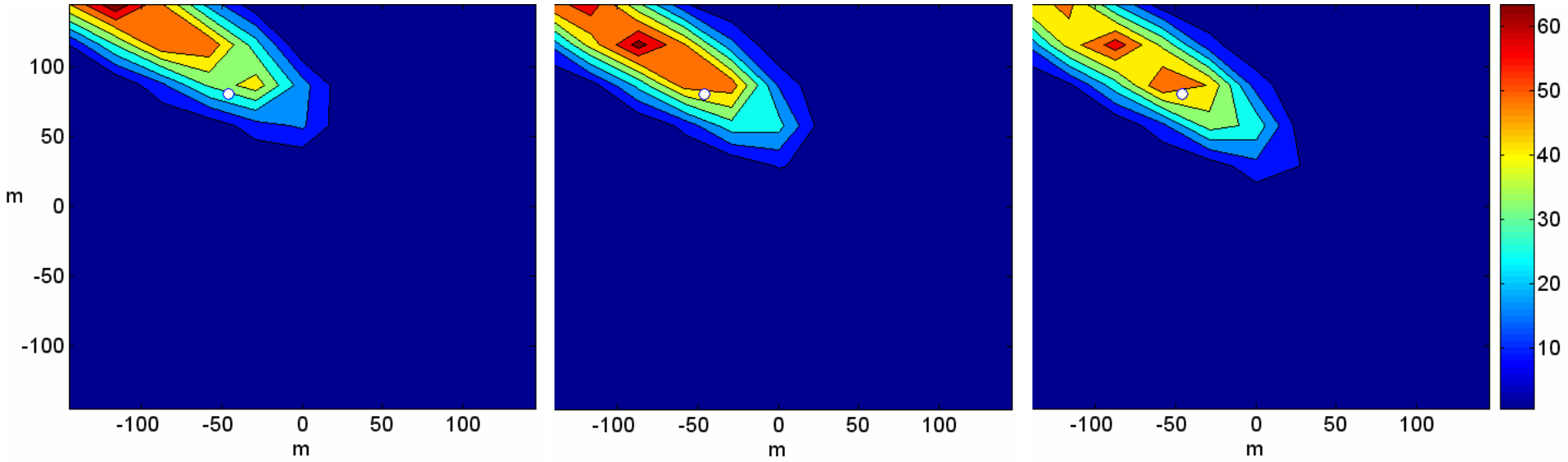


Likelihood Plots (Time Shift)

Time Shift = -10 Sec

Time Shift = 0 Sec

Time Shift = 10 Sec

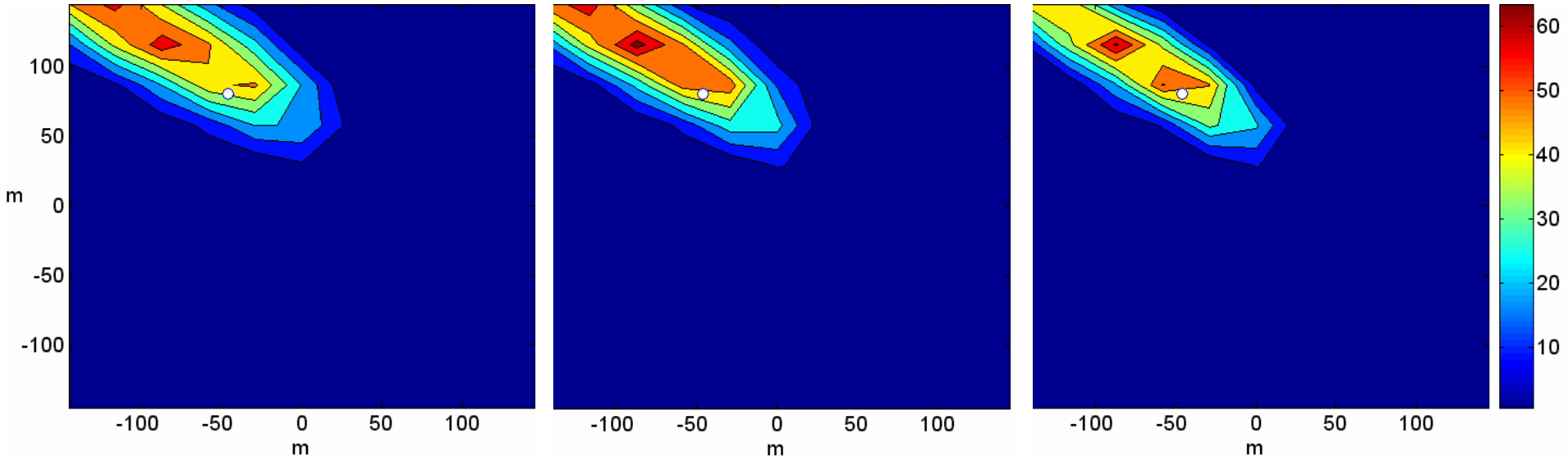


Likelihood Plots (Alarm Level)

$C_{Alarm} = 1x10^{-7}$ kg/m3

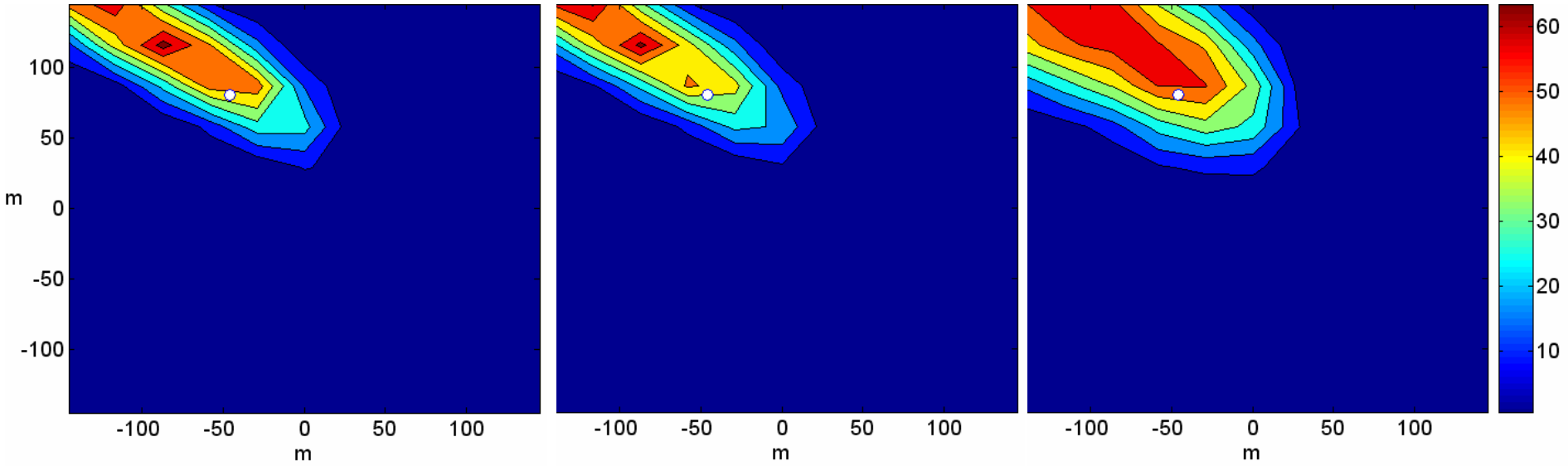
$C_{Alarm} = 3x10^{-7}$ kg/m3

$C_{Alarm} = 9x10^{-7}$ kg/m3



Likelihood Plots (Vel. variance)

T_{Avg} = 0 **T_{Avg} = Default** **LSV 1m/s**



Concluding Remarks

- Simple likelihood measure can be constructed for
  - multiple realistic alarms
  - based on two-point space-time correlation
- Measure is sensitive to
  - alarm level relative to concentration signal
  - assumed turbulence / uncertainty
  - quality of model prediction
- Future work
  - validate/improve correlation estimates
  - test for other scenarios
  - link to optimizing scheme