Evaluation of the Performance of Air Quality Models Using Tracer Experiments

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- Objectives and Motivation
- Field Studies
- Analysis of Meteorology
- Model Formulation
- Model Evaluation
- Conclusions

Research Objectives

- Develop models for dispersion in urban areas at distances ranging from meters to kilometers

- Conduct field studies to collect data for evaluating these models

California Air Resources Board needs a model to examine Environmental Justice issues

Environmental Justice Issues in Barrio Logan
Communities next to freeways

A Mixed Zone Community

Small Neighborhood Businesses among Residences

Sources Near Residents

Field Experiments

Tracer studies designed to study dispersion at scales of meters to kilometers in urban areas.

- Near source experiment at Memorial High, Barrio Logan, April 2001
- CE-CERT parking lot study, April-May 2001
- Dugway Proving Grounds Model Study- July 2001
- Summer and winter Barrio Logan field studies-August and December 2001
- Wilmington shoreline dispersion study-Summer 2004

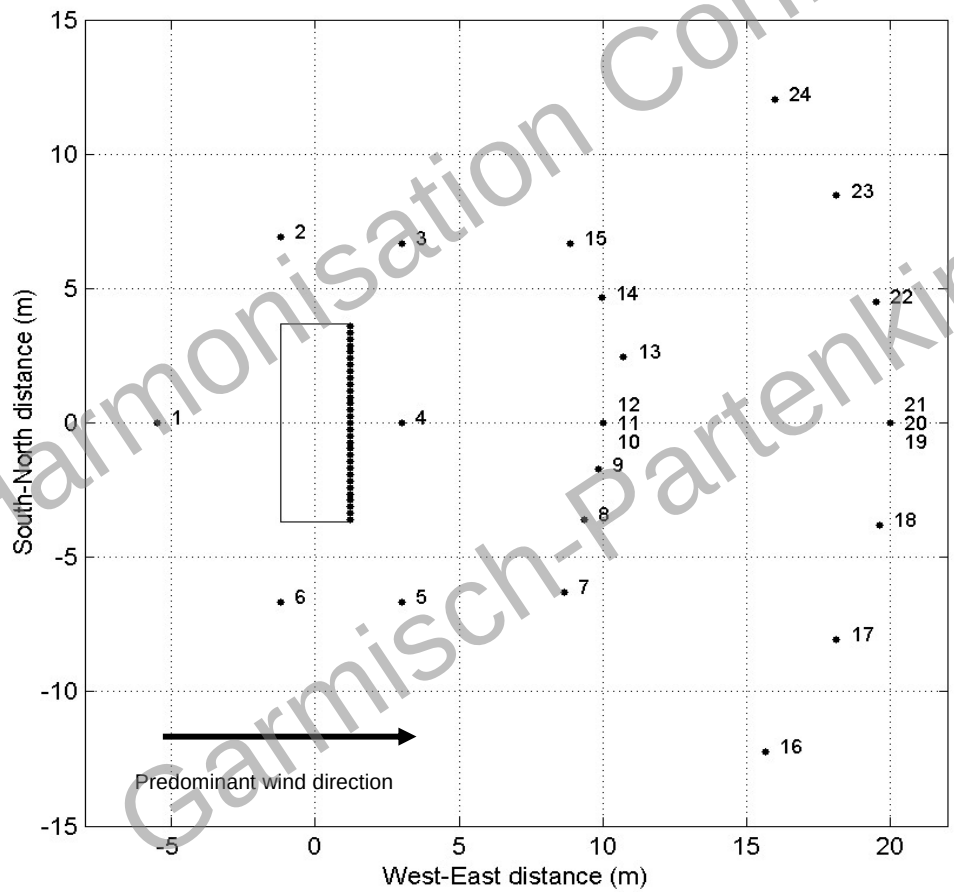
Dugway Experiment

CE-CERT Experiment

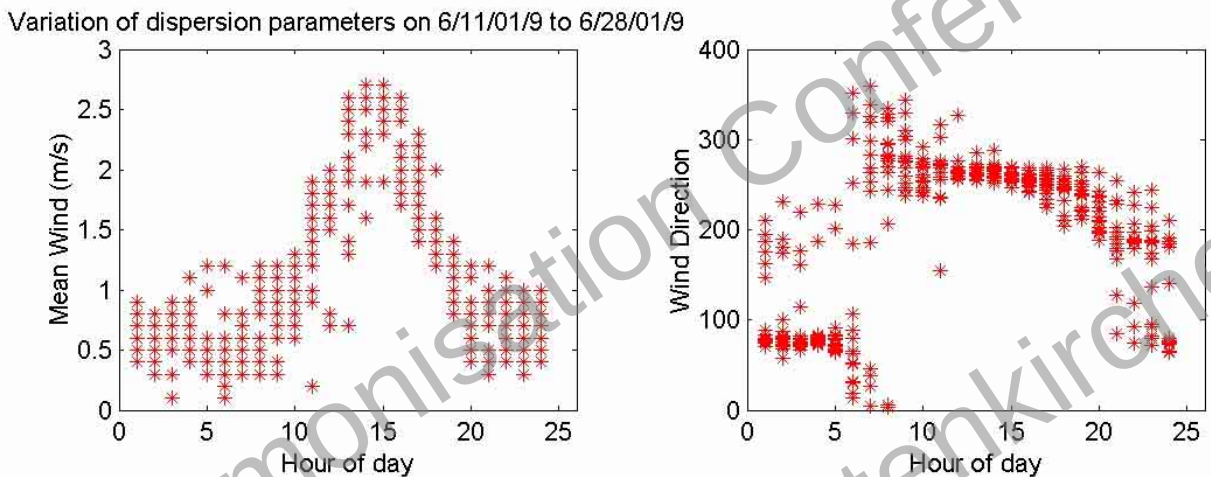
- SF_6 released from line source on the roof of trailer (3.2 m) located in a parking lot
- Conducted during 6/11/01 to 6/28/01 and concentrations monitored continuously
- Concentrations sampled at 24 locations on 3 arcs at 3 m, 10m, and 20 m from the source
- Meteorology measured with sonic anemometer at 3 m on the 10 m arc.

CE-CERT Parking Lot

CE-CERT Parking Lot



Meteorology



Model Evaluation

The data were used to evaluate 4 models:

1. AERMOD-PRIME
2. ISC-PRIME
3. AERMOD-Volume source
4. AQMM

AERMOD Treatment

The horizontal distribution is written as:

$$H(x,y) = f_{ran}\frac{1}{2\pi r} + (1 - f_{ran})\frac{1}{\sqrt{2\pi}\sigma_y}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)$$

$$f_{ran} = \frac{2\sigma_v^2}{2\sigma_v^2 + u_m^2} = 2\left(\frac{\sigma_y}{x}\right)^2$$

Air Quality Model with Meandering AQMM

$$\frac{C}{Q} = \frac{P(\theta)}{U_\theta r} S(z)$$ Venkatram (1988), Hanna (2003)

$$S(z) = \sqrt{\frac{2}{\pi}} \frac{1}{\sigma_z} \exp\left(-\frac{h_s^2}{2\sigma_z^2} \right)$$

$$\sigma_z = \frac{\sigma_w r}{U_\theta} + \frac{h_s}{2}$$

Simulating P(θ)

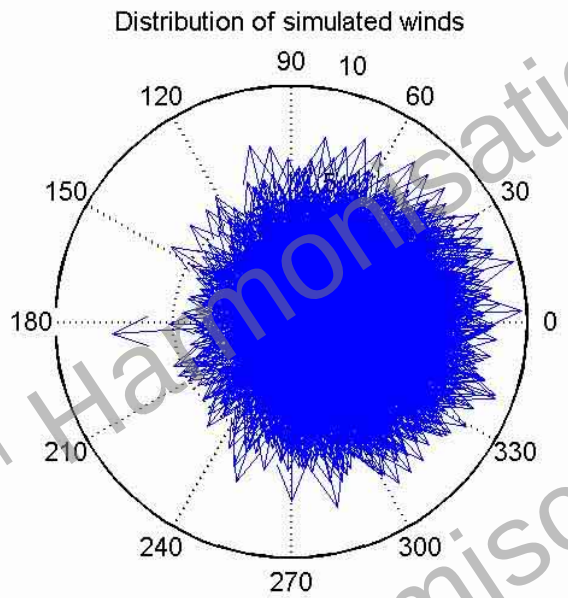
$$u = \bar{u} + u' \; ; \; v = v'$$

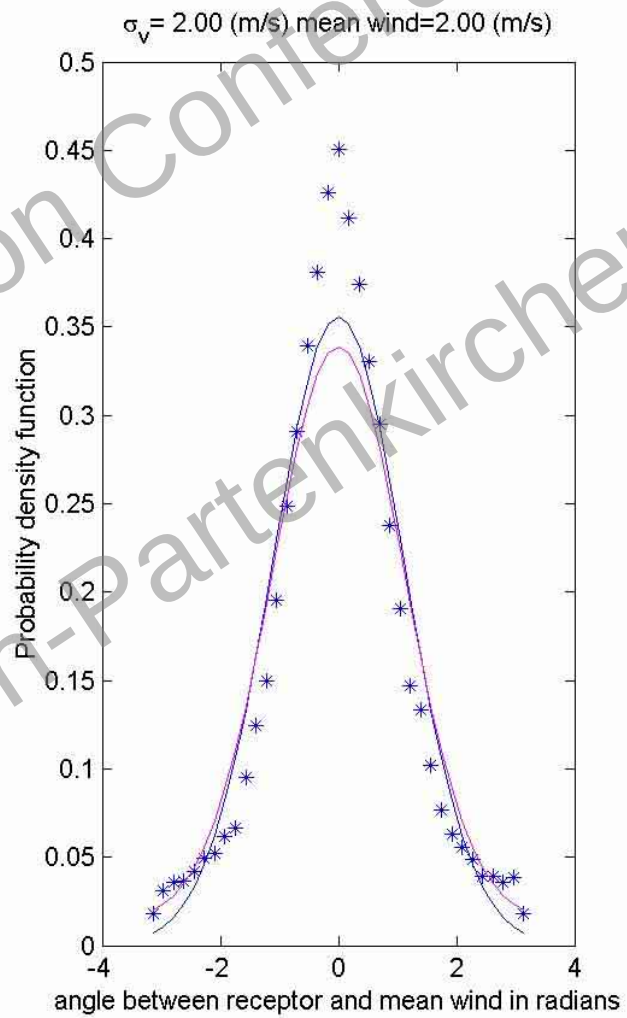
$$(u', v') = N(0, \sigma_v)$$

$$\theta = \tan^{-1}\left(\frac{v}{u}\right)$$

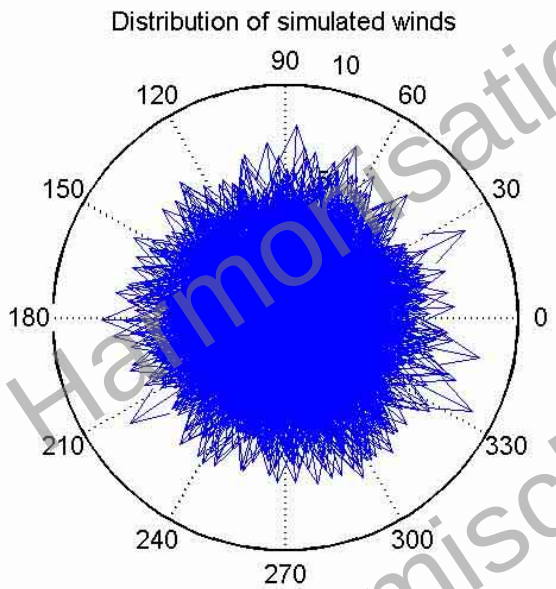
$$U_\theta = \left(u^2 + v^2\right)^{1/2}$$

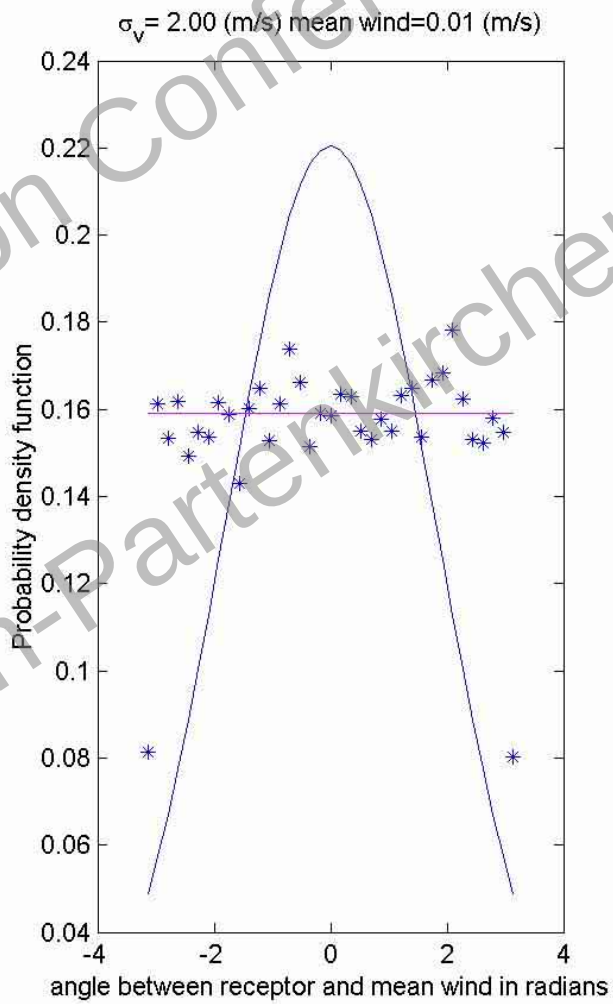
Simulating P(θ)





Simulating P(θ)





Results from Simulations

$$\bar{U}_\theta = \left(u_{mean}^2 + 2\sigma_v^2 \right)^{1/2}$$

$$\sigma_\theta = \sigma_{\theta max} \tanh\left(\frac{\sigma_v}{u_{mean}} \frac{l}{\sigma_{\theta max}} \right)$$

$$\sigma_{\theta max} = \frac{\pi}{\sqrt{3}}$$

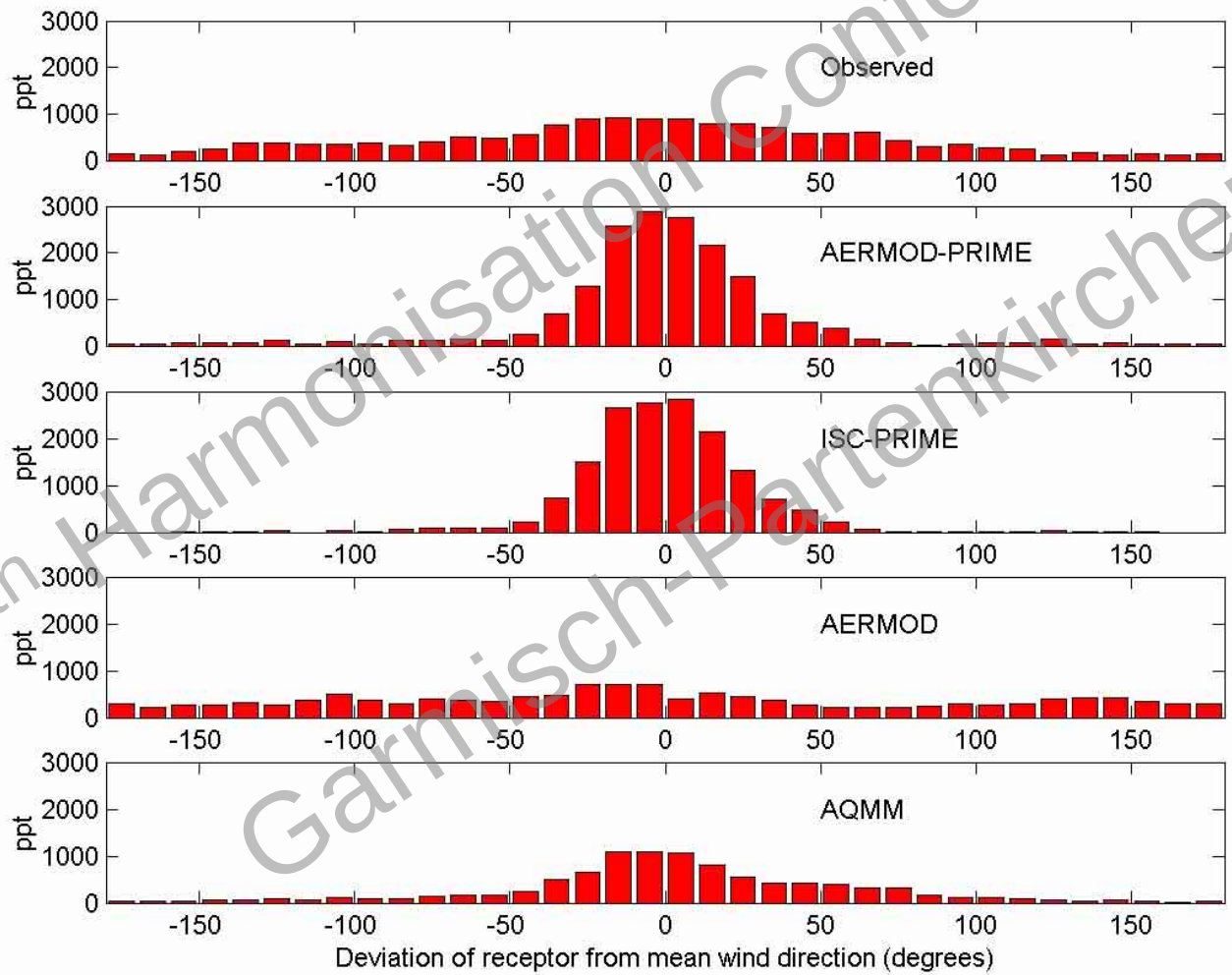
Results from Simulations

$$P(\theta) = f P_{gauss}(\theta) - (1 - f) P_{uniform}$$

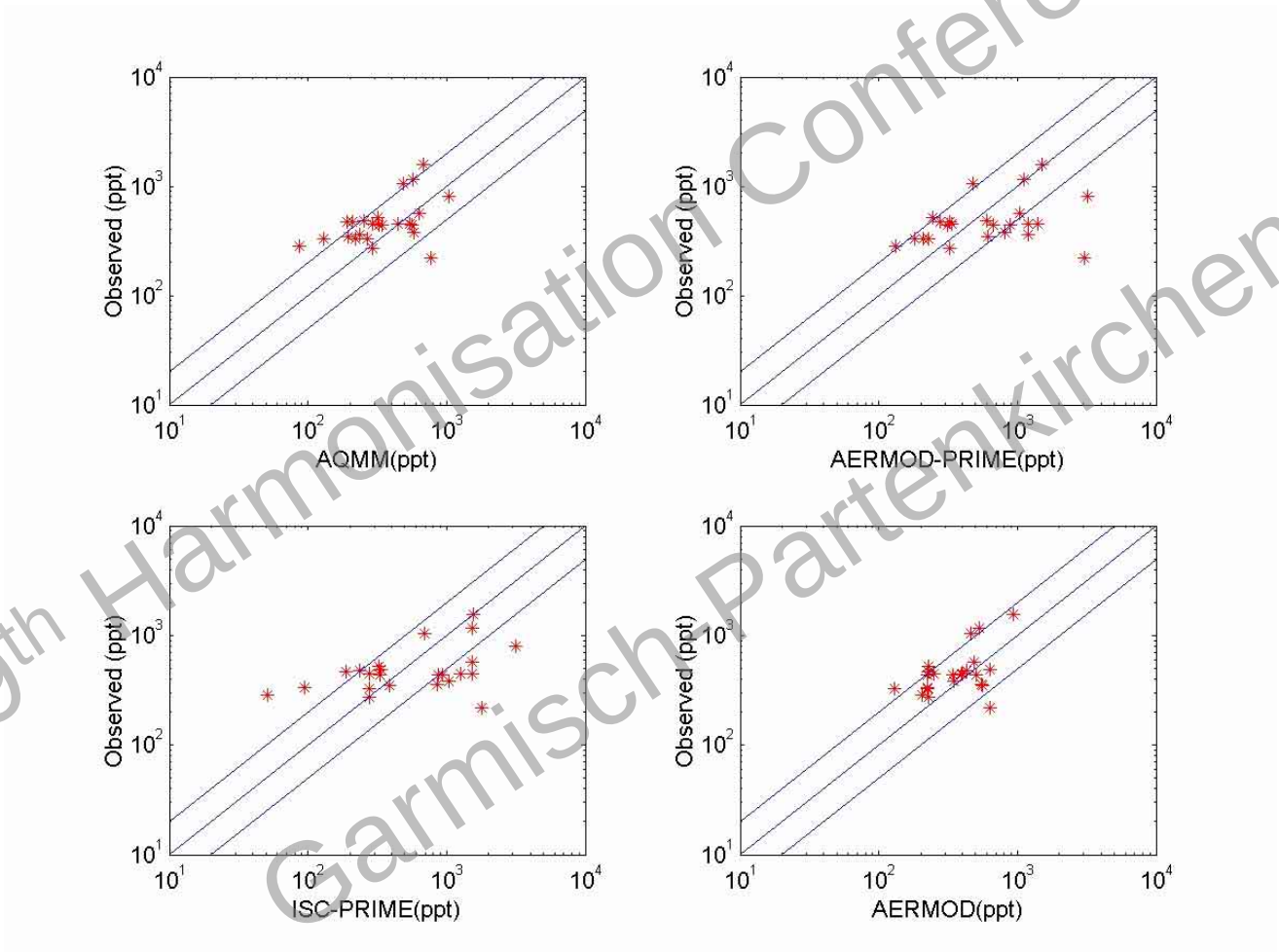
$$P_{uniform} = \frac{1}{2\pi}$$

$$f = \exp\left(-0.09 \frac{\sigma_v}{u_{mean}} \right)$$

Model Evaluation Results

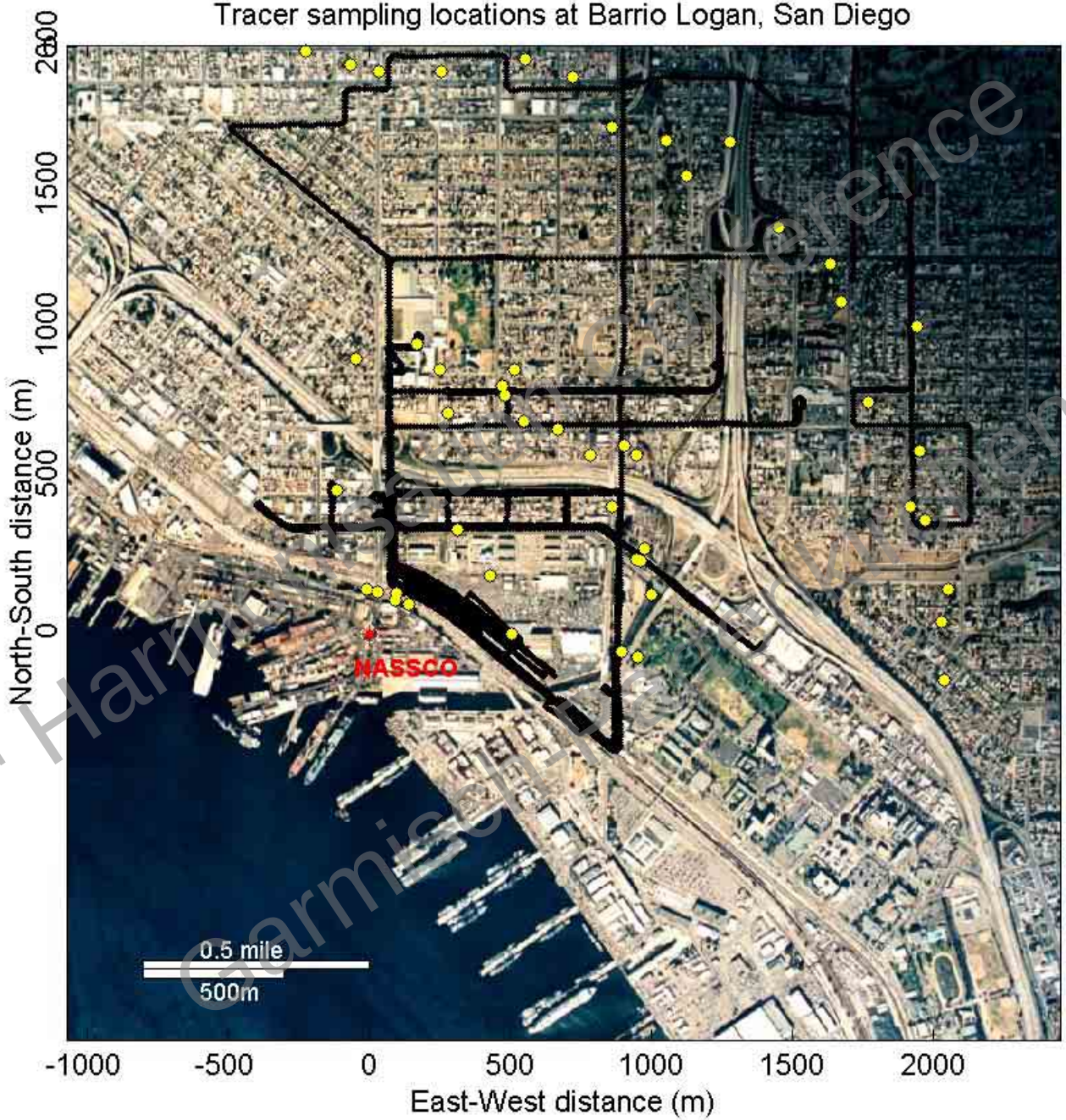


Spatial Distributions



Barrio Logan Experiment

- SF_6 released from 5 m point source at shipyard
- Conducted during 8/21/01 to 8/31/01 and concentrations sampled over 10 hours for 5 days
- Concentrations sampled at 50 locations on 4 arcs at 200 m, 500 m, 1000 m and 2000 m from the source
- Plume tracked with mobile monitor
- Meteorology measured with sonic anemometers and minisodar on 1000 m arc



SF_6 Release Location

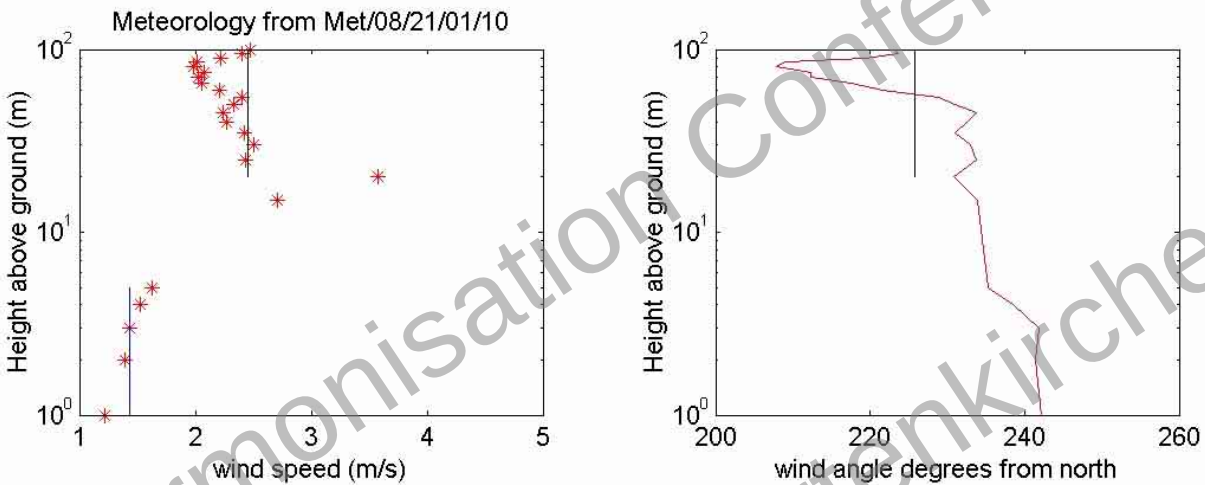
Sand box in center of photo

Sampler (Bag), Residence

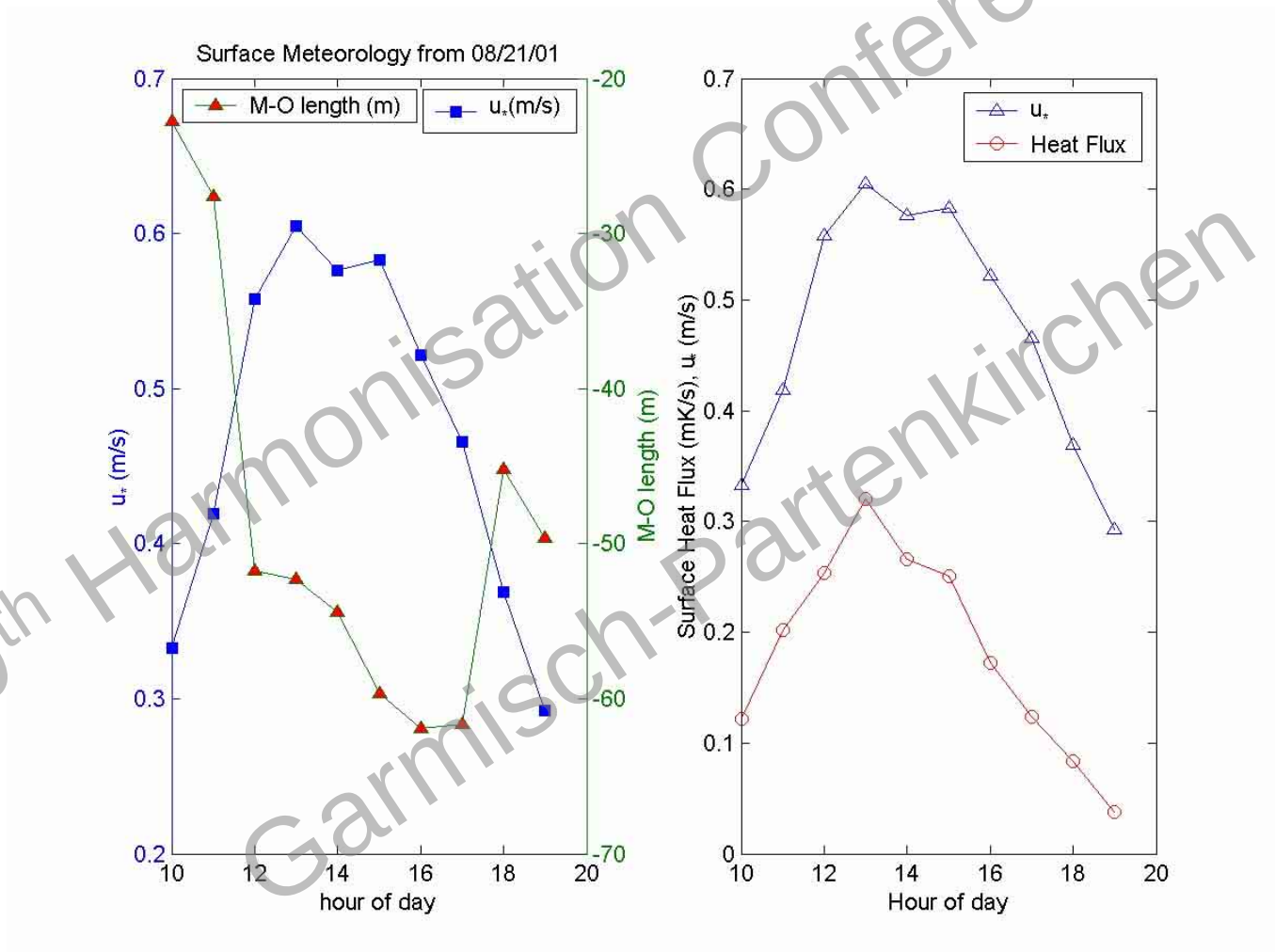
Near Field Tracer Experiment in Wilmington, 09/2003

Mobile Sampler

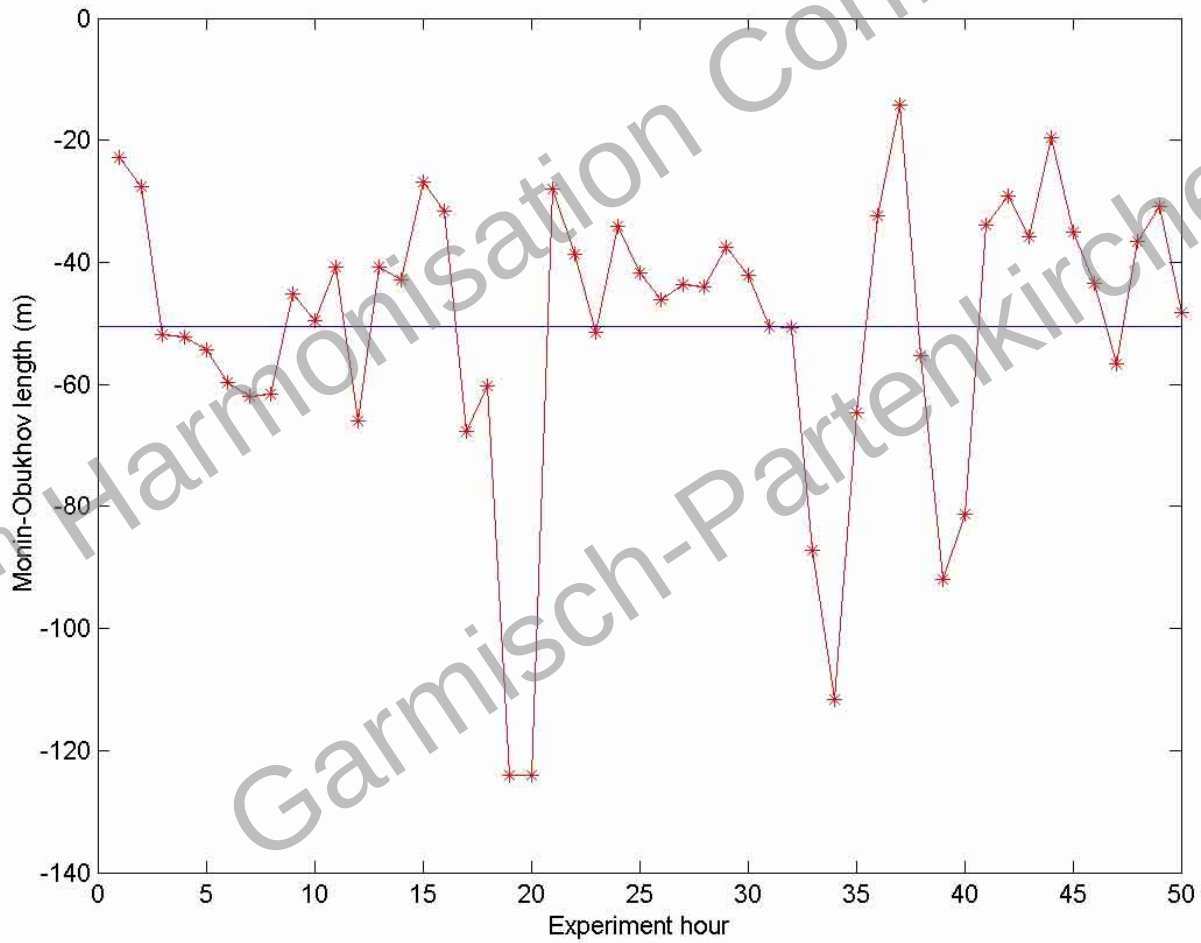
Turbulence and Wind Profiles



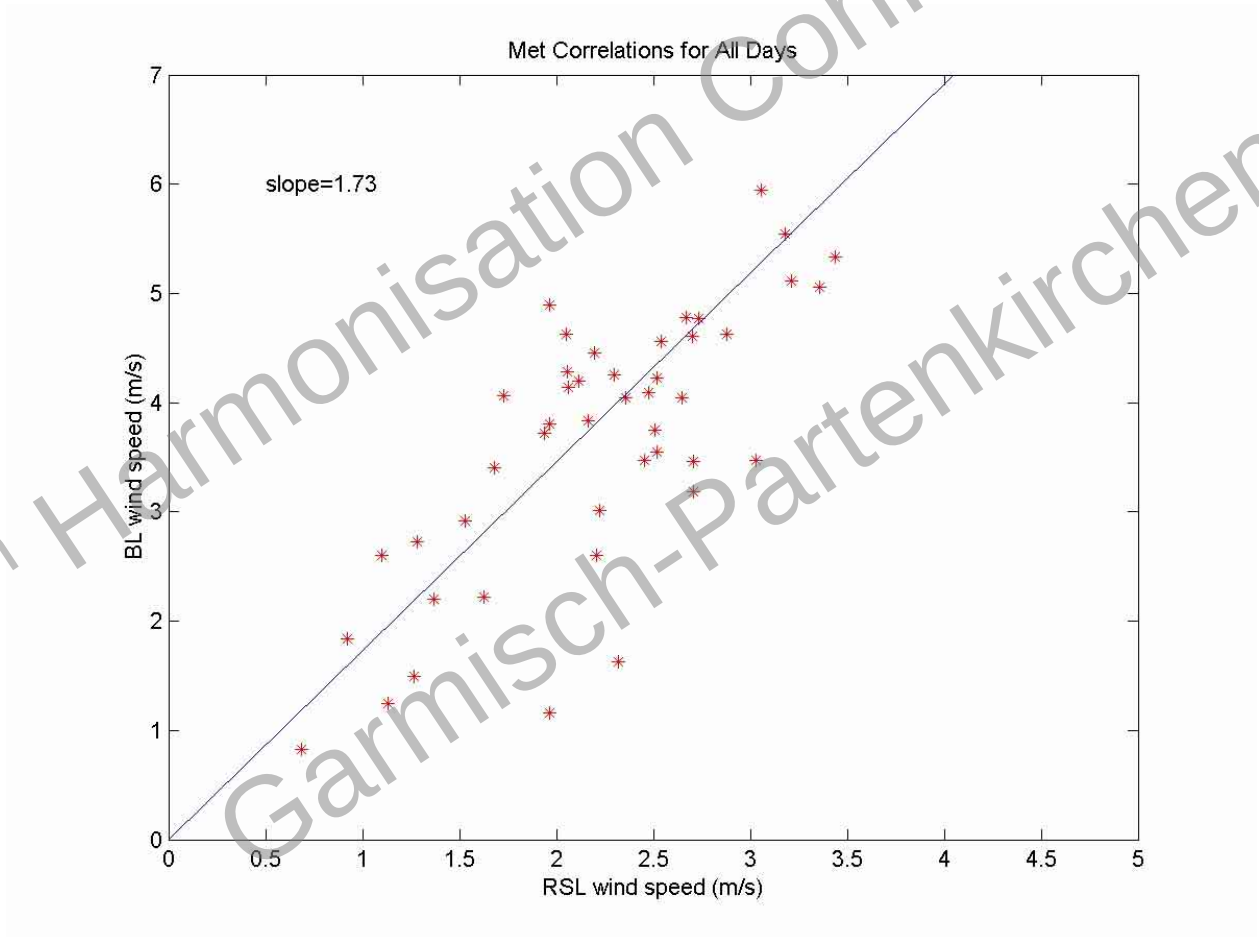
Surface Meteorology



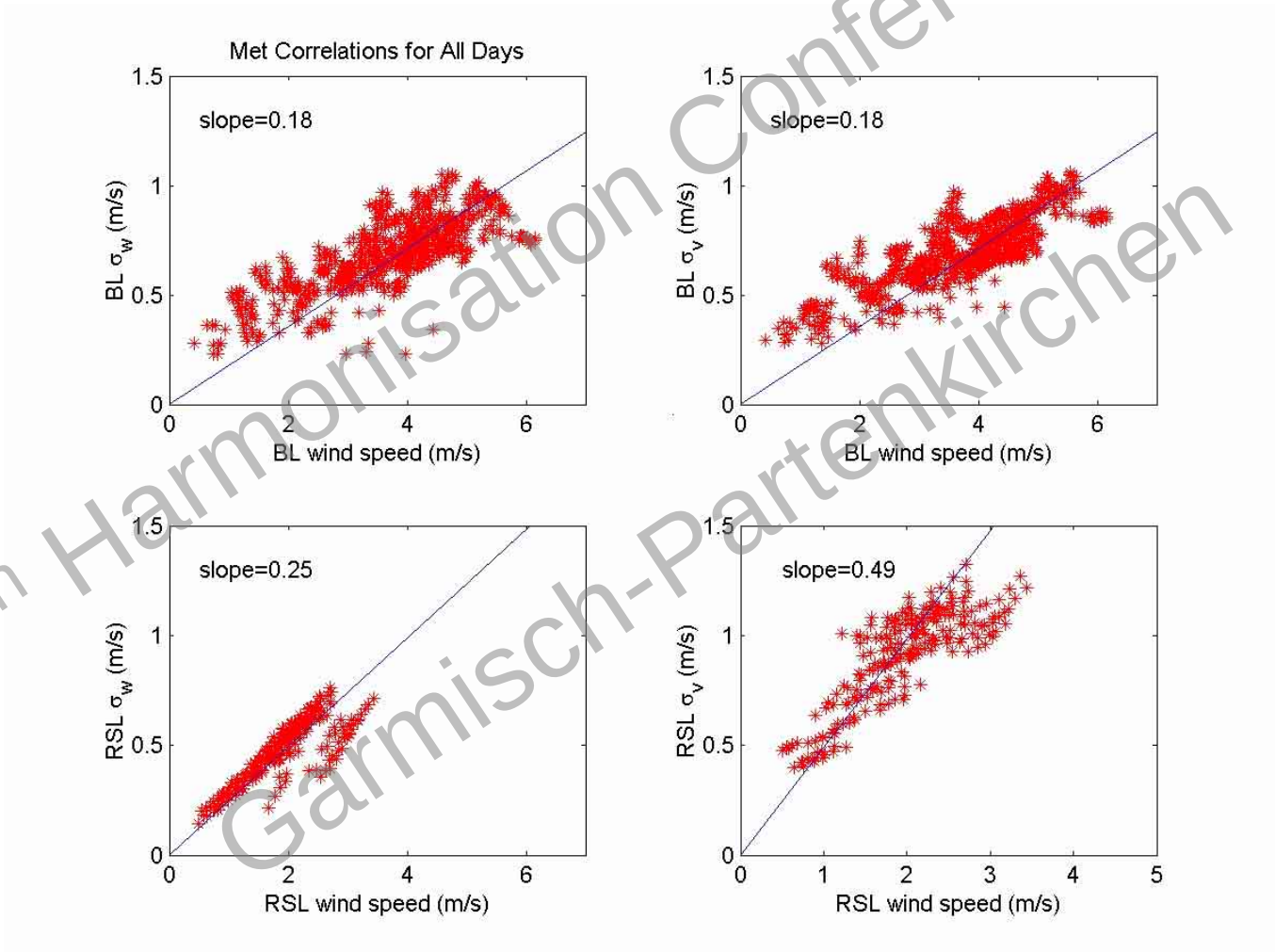
M-O Length Variation



Analysis of Meteorology



Meteorological Correlations in Barrio Logan



Parameterizations for σ_w and σ_v

Gryning et al. (2004)

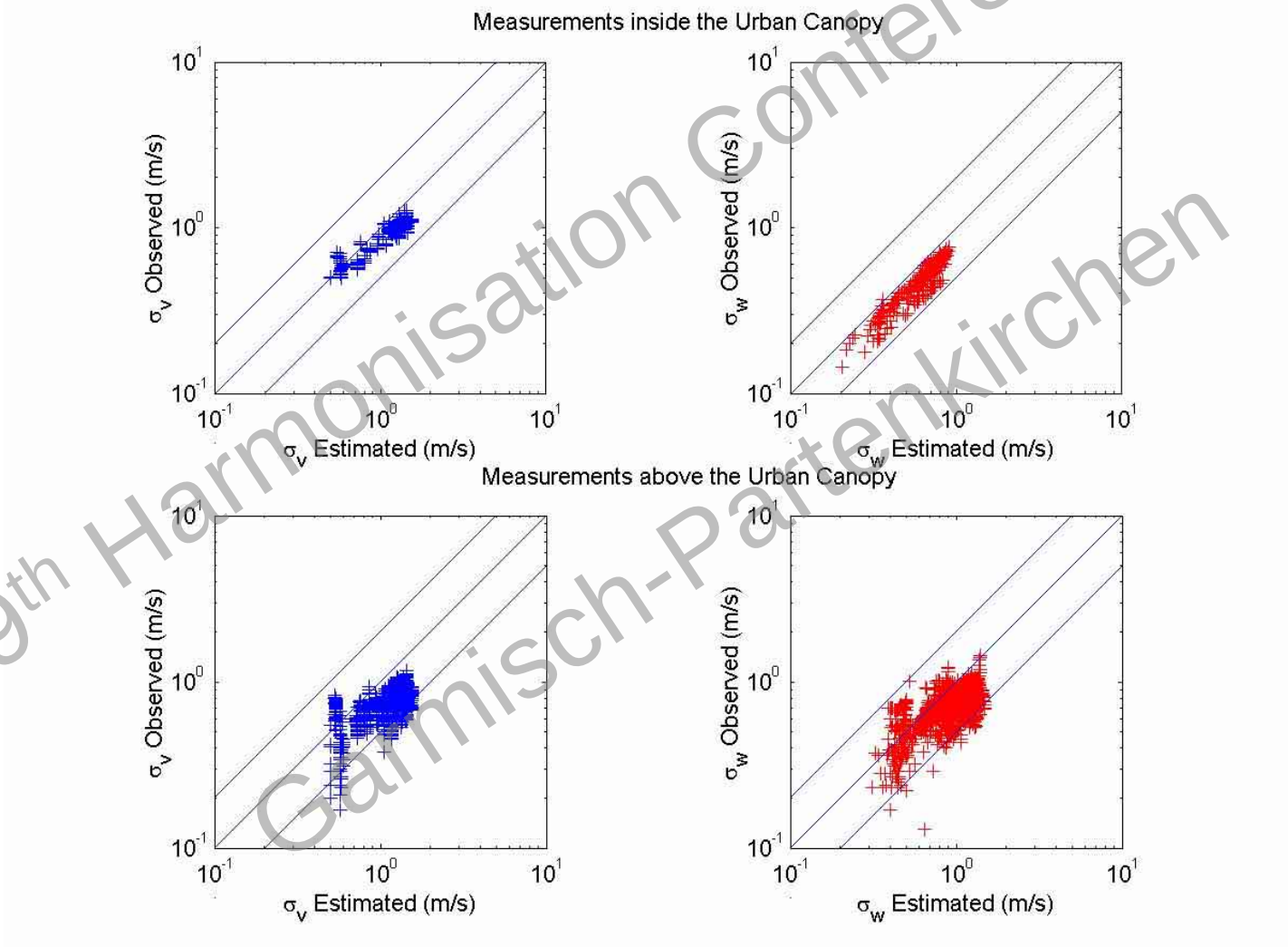
$$\sigma_w^2 = 1.5u_f^2 \exp\left(-2\frac{z}{z_i}\right) + u_*^2\left(1.7 - \frac{z}{z_i}\right)$$

$$\sigma_v^2 = 0.35w_*^2 + u_*^2\left(2 - \frac{z}{z_i}\right)$$

$$w_* \equiv \left(\frac{g}{T_o}Q_o z_i\right)^{1/3}$$

$$u_f \equiv \left(\frac{g}{T_o}Q_o z\right)^{1/3}$$

Performance of Parameterizations



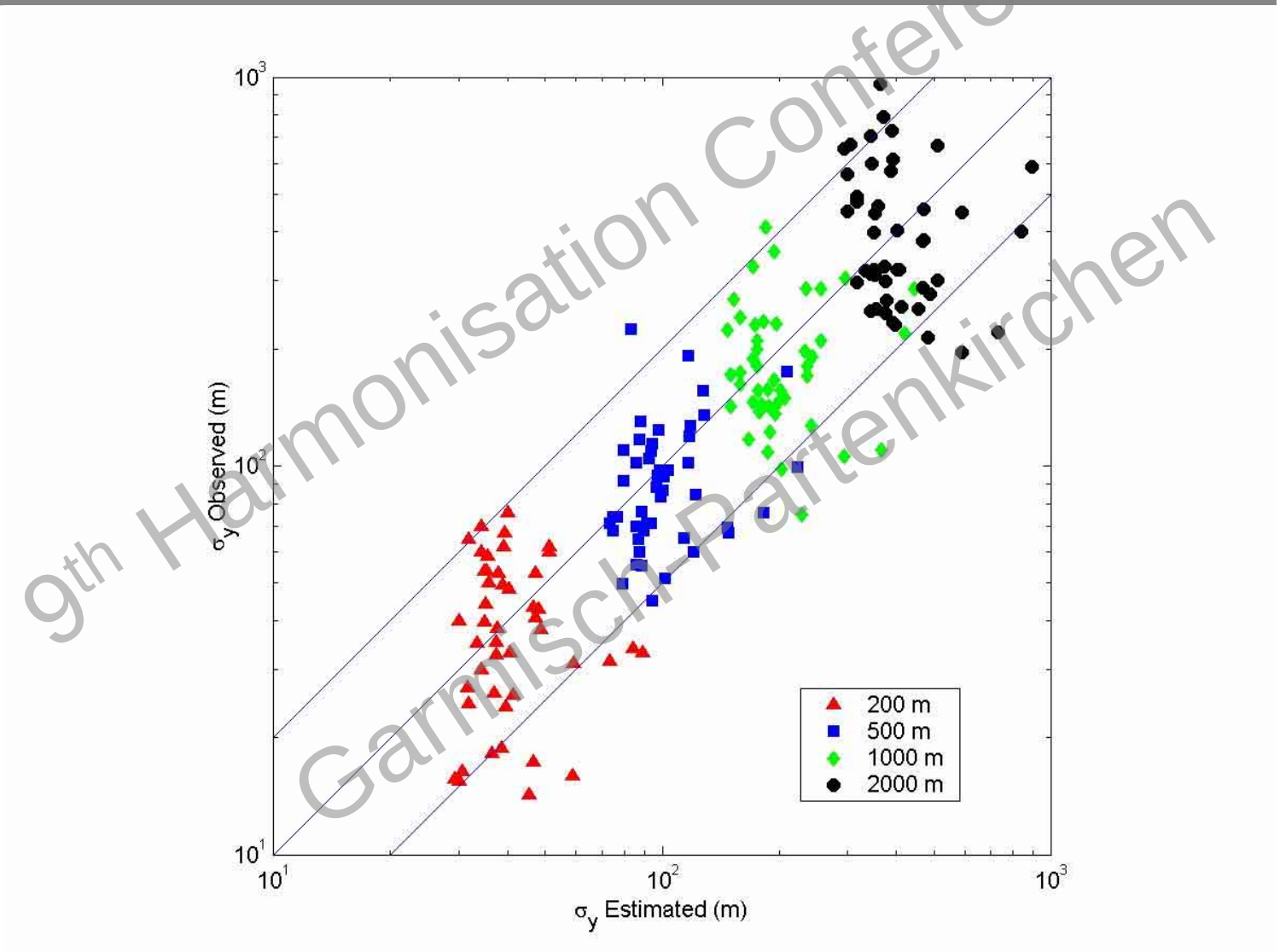
Dispersion Model

$$C(x,y,0) = \frac{Q}{\pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)$$

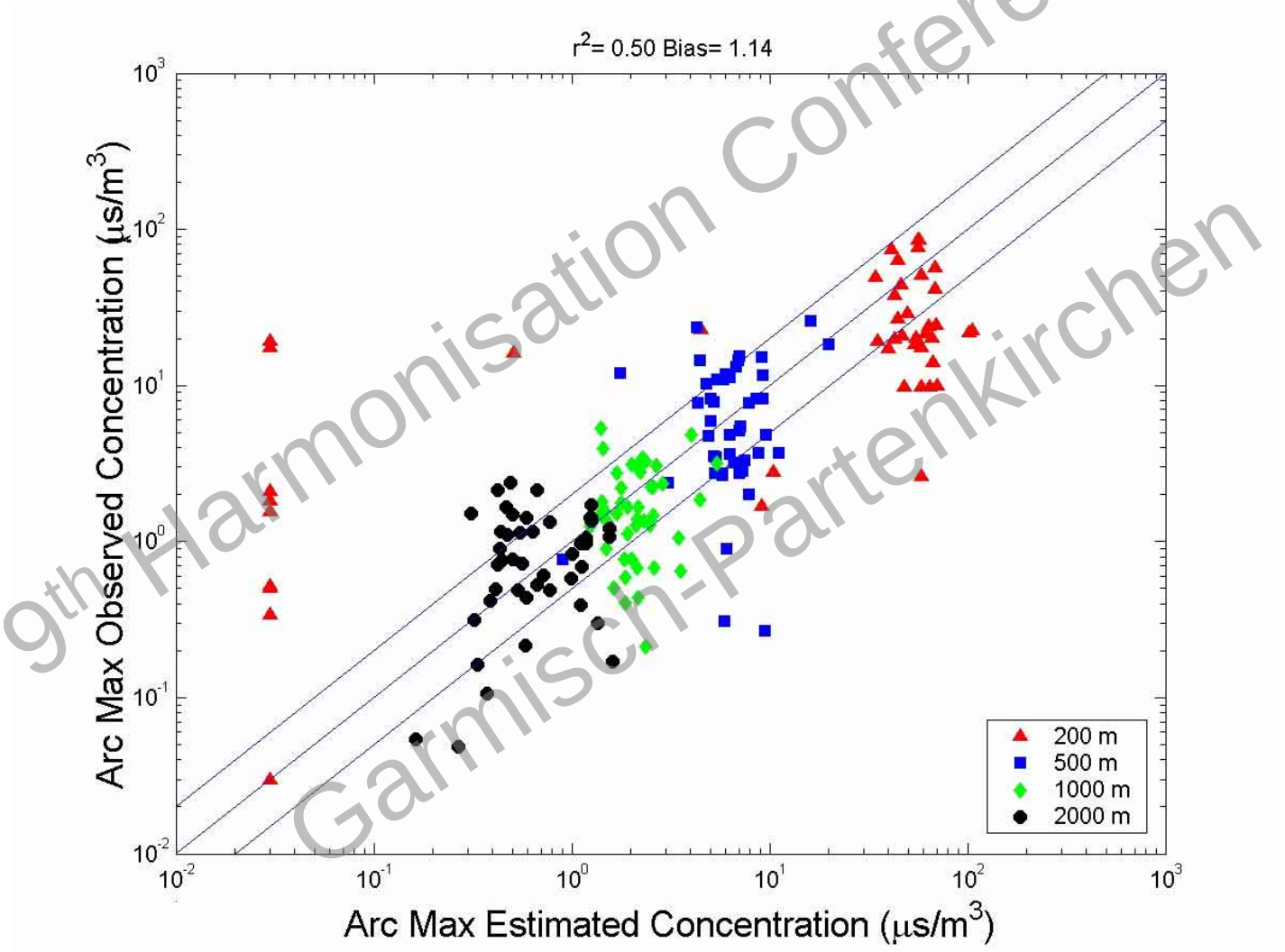
$$\sigma_y = \sigma_{yo} + \frac{\sigma_v x}{U}$$

$$\sigma_z = \frac{\sigma_w x}{U}\left(1 + \frac{x}{50|L|}\right)^{1/2}$$

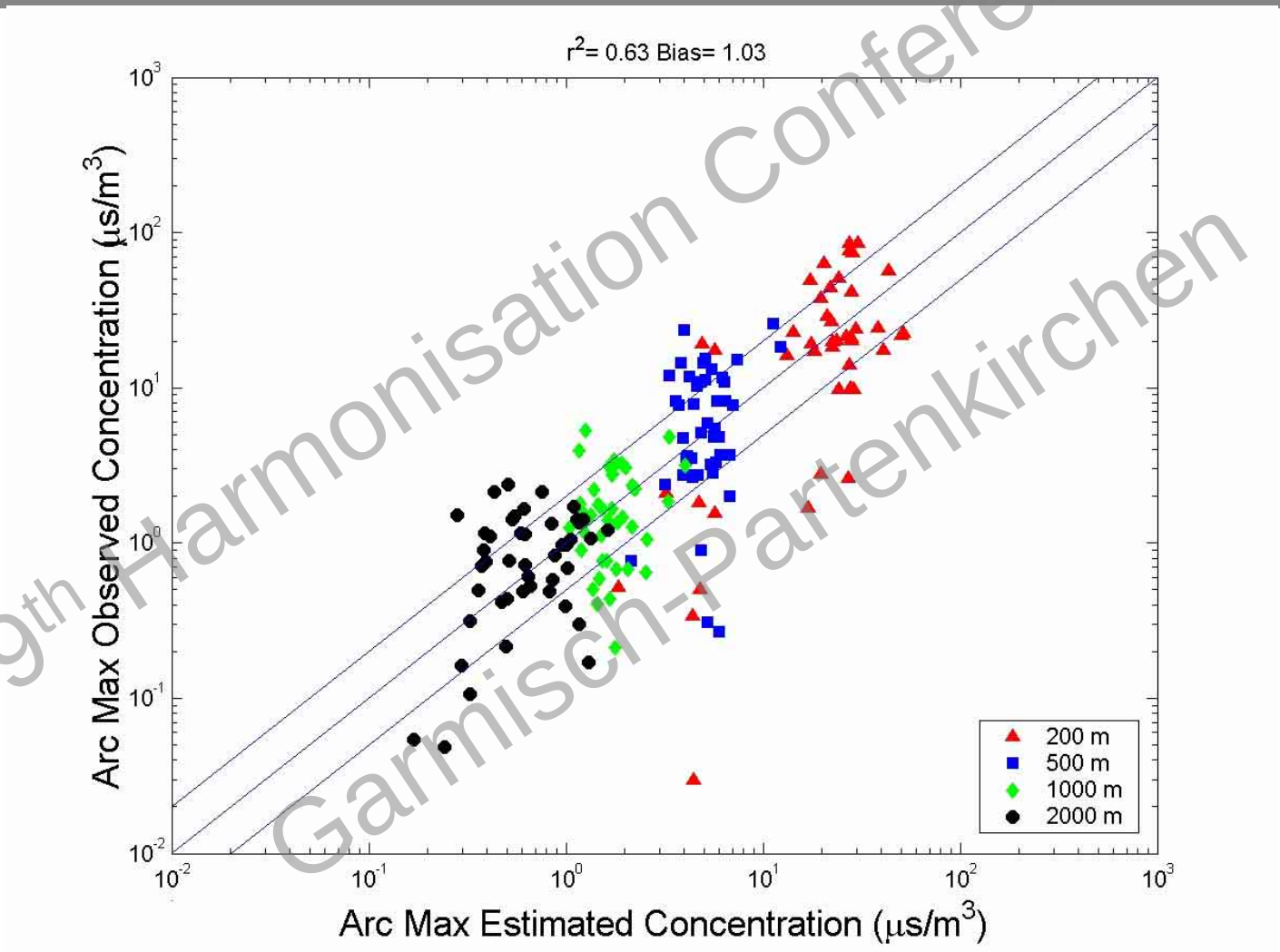
Horizontal Plume Spread



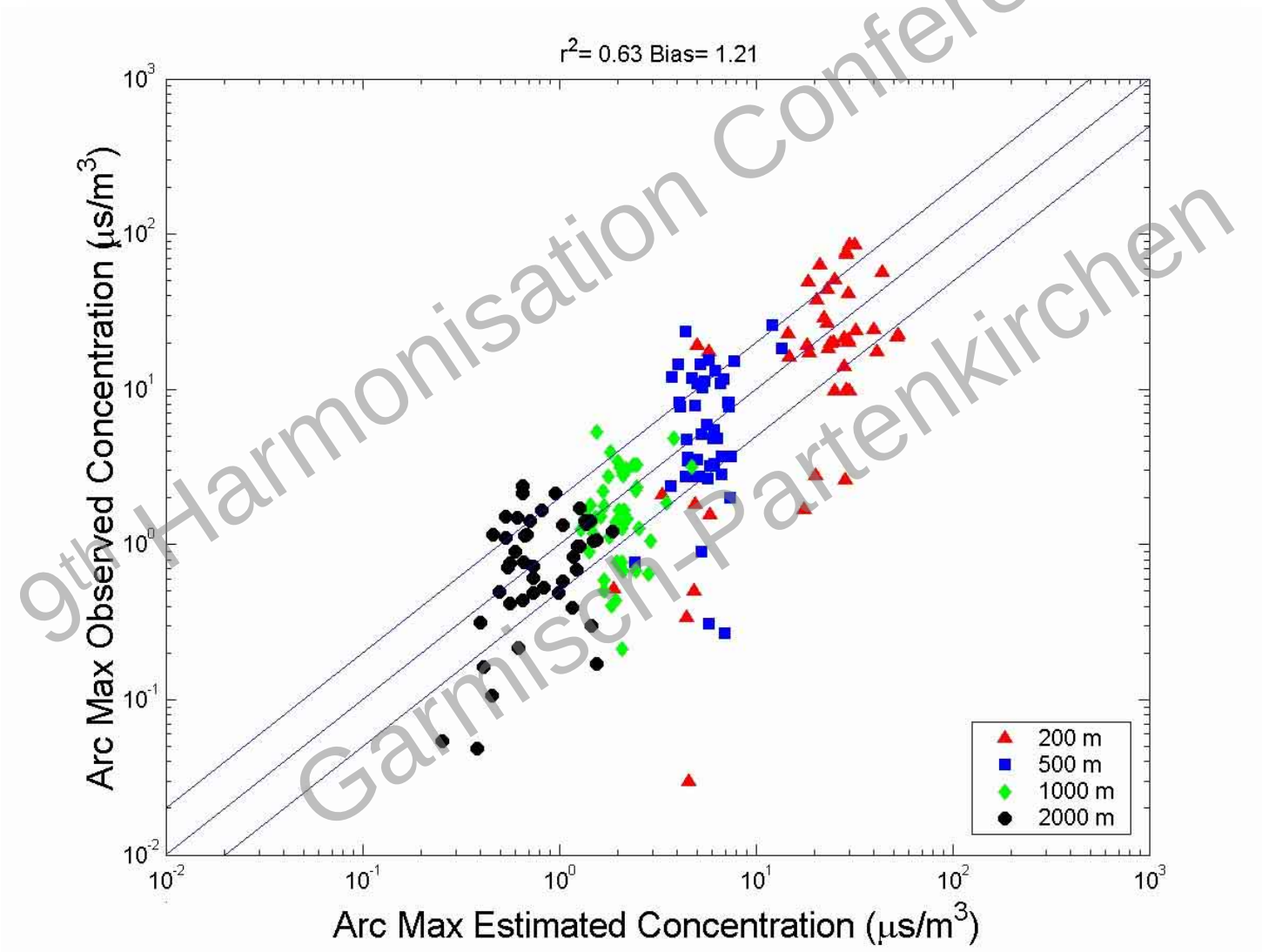
Model Results Using Boundary Layer Information and No Initial Spread



Model Results using Boundary Layer Information with Initial Spread



Model Results Neglecting Stability Effects



Empirical Model

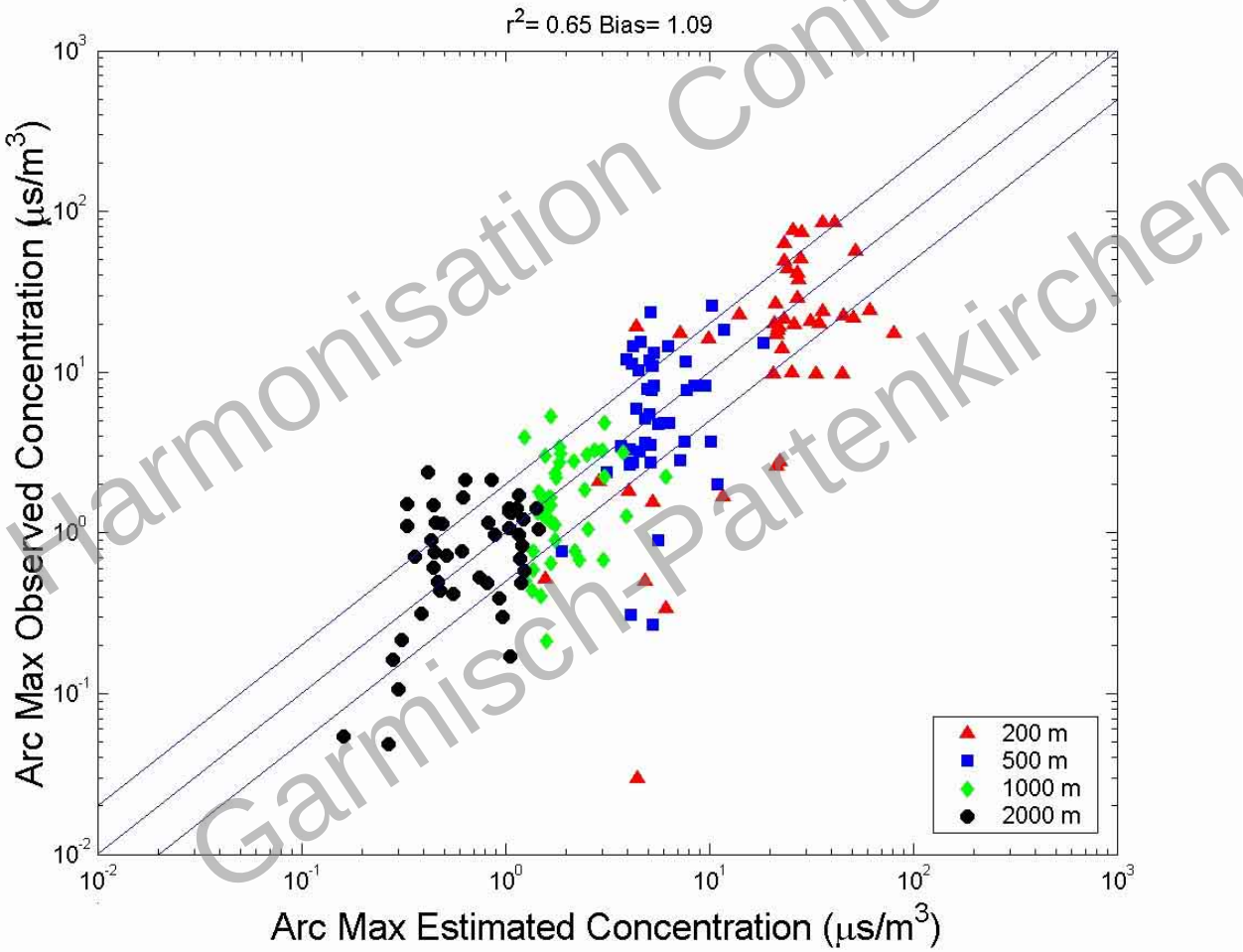
$$C(x,y,0) = \frac{Q}{\pi U \sigma_y \sigma_z} \exp\left(-\frac{y^2}{2\sigma_y^2}\right)$$

$$\sigma_y = 50 + 0.18x$$

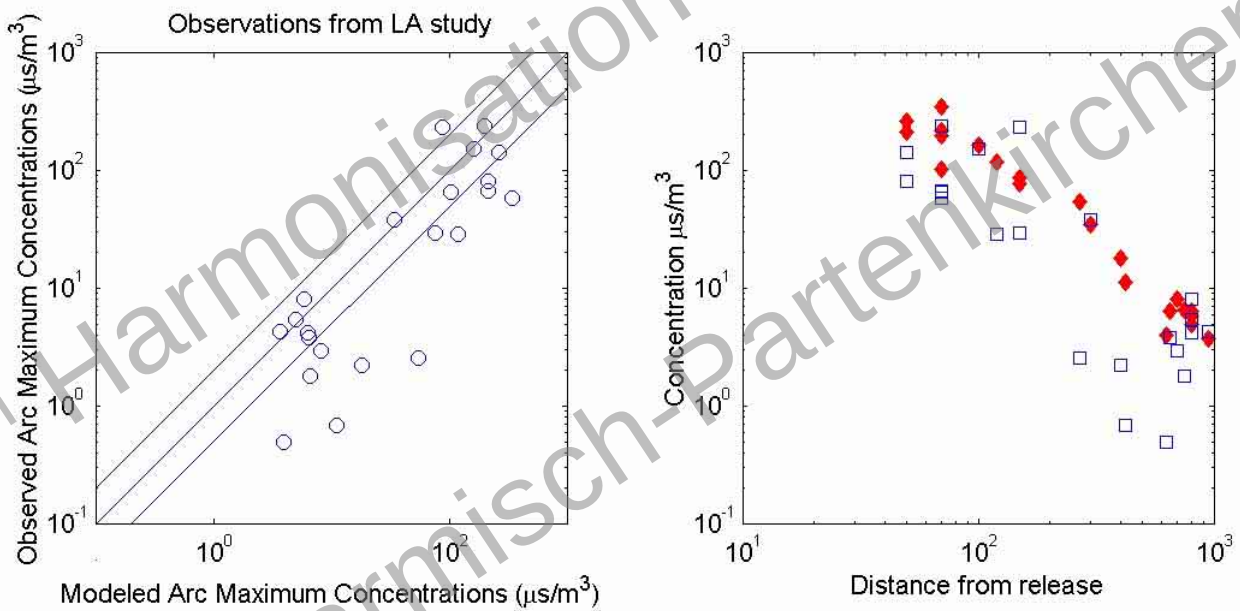
$$\sigma_z = 0.18x\left(1 + \frac{x}{2500}\right)^{1/2}$$

$$U = 1.73U_{5m}$$

Model Results using Empirical Model



Model Performance for LA Experiment



Concentration Variation

$$C_{max} = \frac{Q}{\pi U_{dil} x^2 \left(1 + x/L\right)^n}$$

$$U_{dil} = \frac{\sigma_w \sigma_v}{U} \approx 0.06 U_{5m}$$

Conclusions

- Dispersion models should account for magnification of horizontal spread near sources- channeling ?
- Turbulence above the canopy controls dispersion once the plume spread exceeds canopy height
- Simple models for dispersion provide adequate concentration estimates
- Surface based meteorology might allow us to infer boundary layer properties