Estimating Meteorological Inputs for Dispersion Modeling in Urban Areas

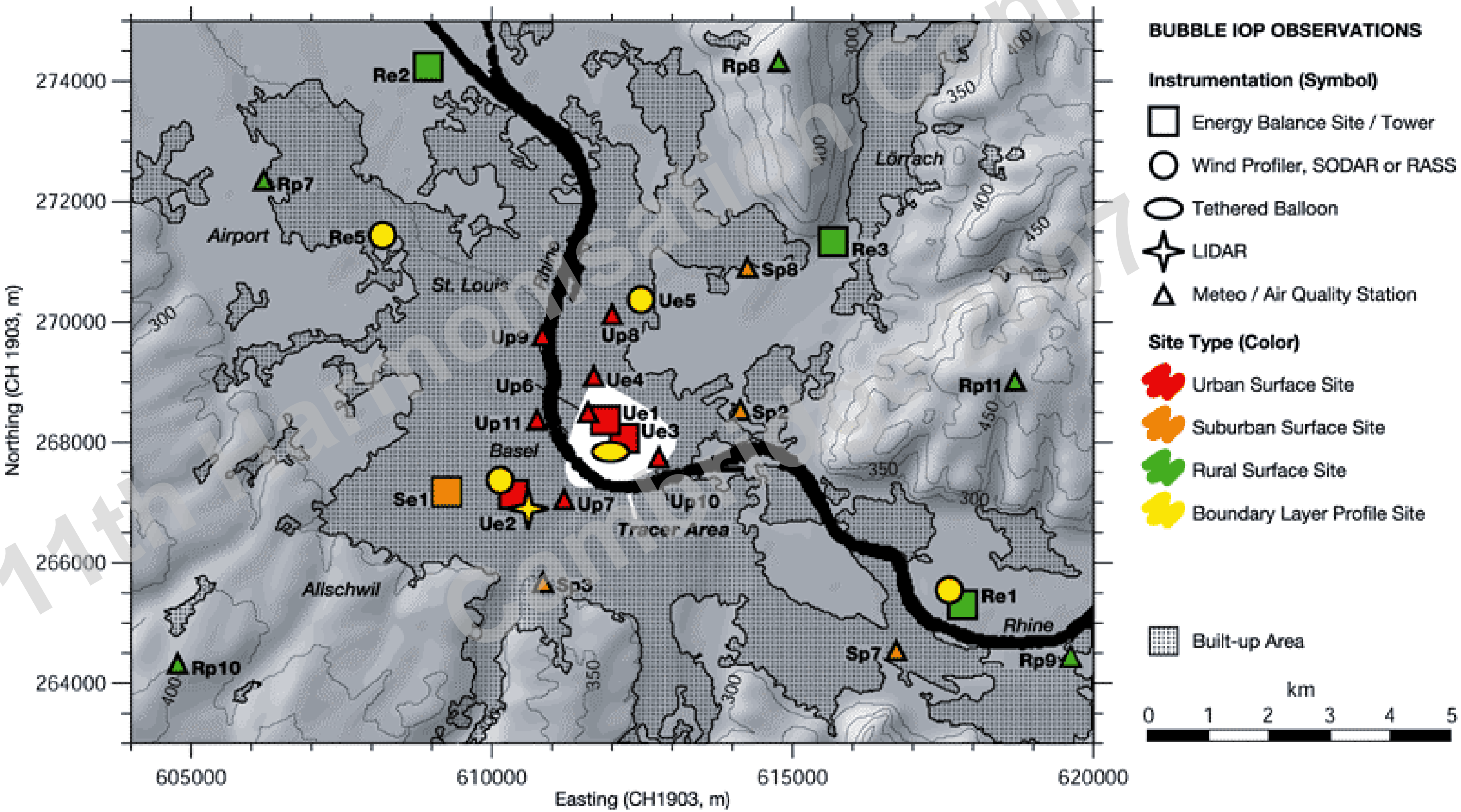
Akula Venkatram, Marko Princevac, Ashok Luhar, Wenjun Qian*
University of California, Riverside
** CSIRO Australia*

- Meteorological models to estimate urban parameters as air flows from rural area to urban area.
  - Comprehensive TAPM-CSIRO, MM-5
  - Simple IBL models
- Measurements of mean winds and temperatures on urban towers to infer micrometeorological variables using M-O theory

TAPM-The Air Pollution Model

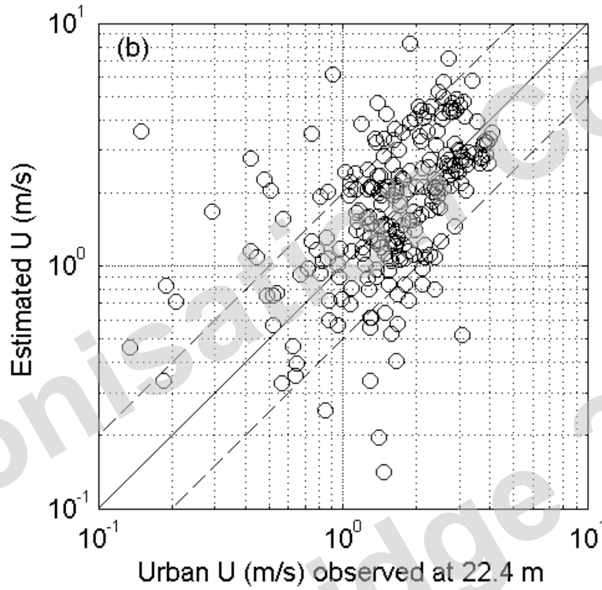
- TAPM used to simulate July 10-11, 2002 during the BUBBLE experiment with fine resolution of 0.5 km.
- The main urban measurements tower, Basel-Sperrstrasse , 32 m high, located inside a street canyon in area with homogeneous, residential building blocks, with mean height of 14.6 m AGL
- The rural site, Village Neuf, located about 6.5 km NNW of the urban site, measured flow and turbulence at 3.3 m AGL over bare soil in an agricultural area (= 0.07 m).

BUBBLE Experiment

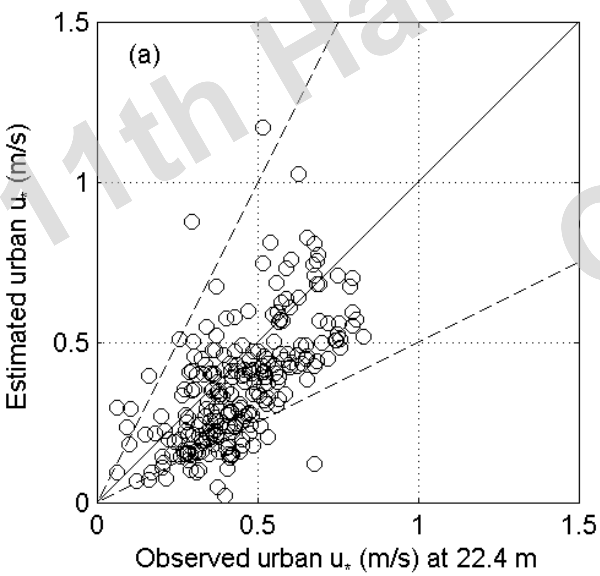


Results from TAPM

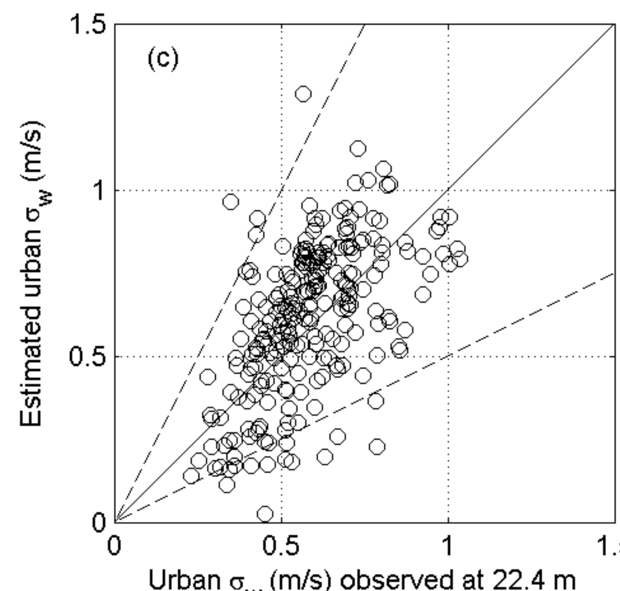
Mean Wind



Friction velocity

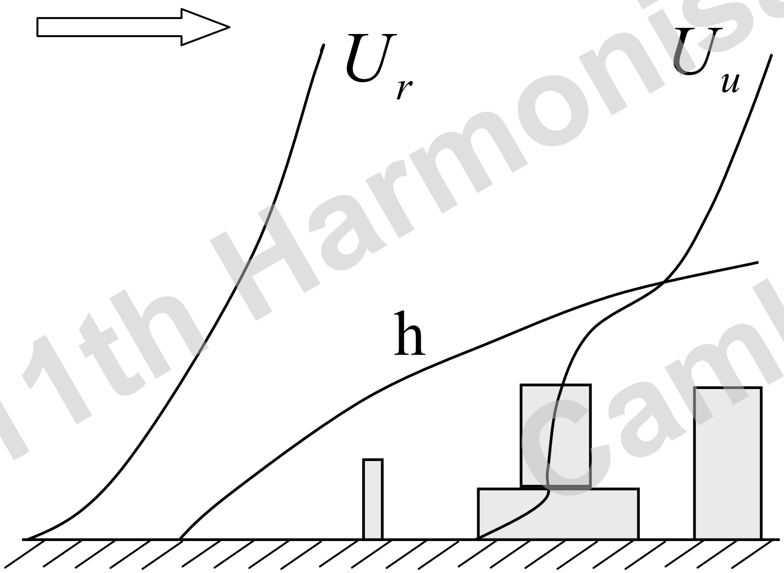


Vertical velocity fluctuations



Internal boundary layer model

Internal boundary layer model



$$\frac{dh}{dx} = \frac{\sigma_w}{U} \varphi\left(\frac{h-d}{L_u}, z_{ou}\right)$$

$$L_u = \infty \text{ when } L_r > 0$$

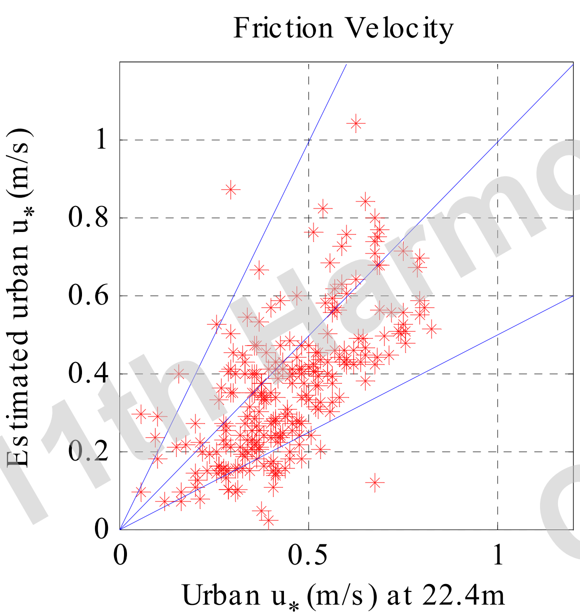
$$L_u = L_r \text{ when } L_r < 0$$

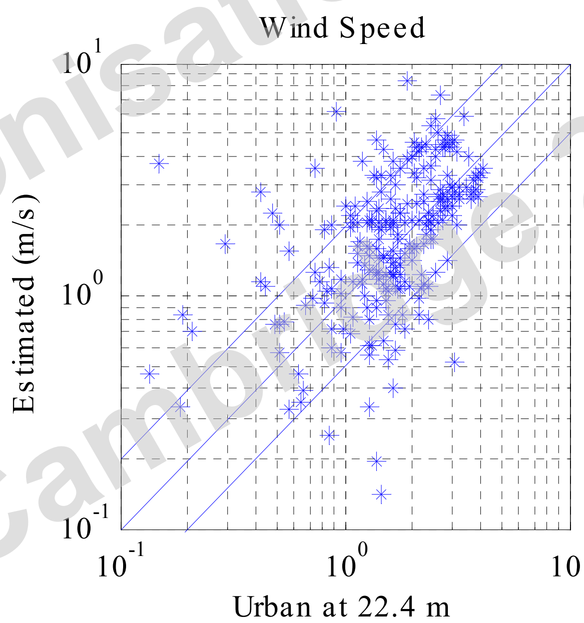
$$U_u(h) = U_r(h)$$

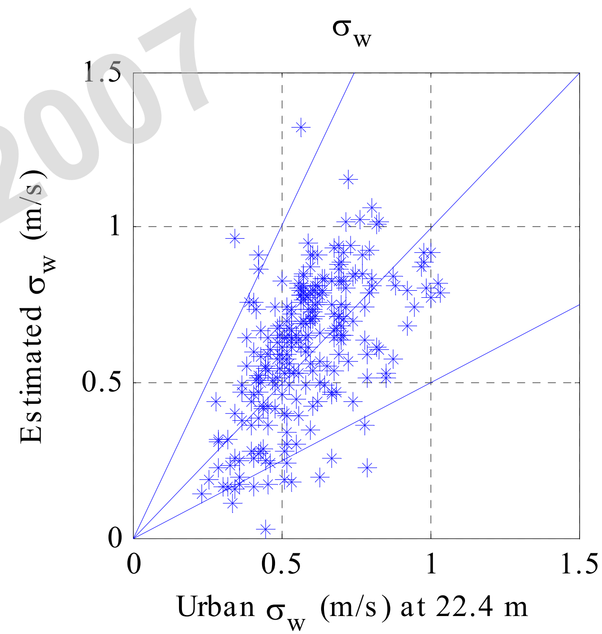
$$u_{*u} = \frac{kU_u(h)}{\ln\left(\frac{h-d}{z_{ou}}\right) + \varphi_m\left(\frac{h-d}{L}, z_{ou}\right)}$$

Evaluating Urban Micrometeorological Variables with IBL model

Measurements at BSPR from BUBBLE







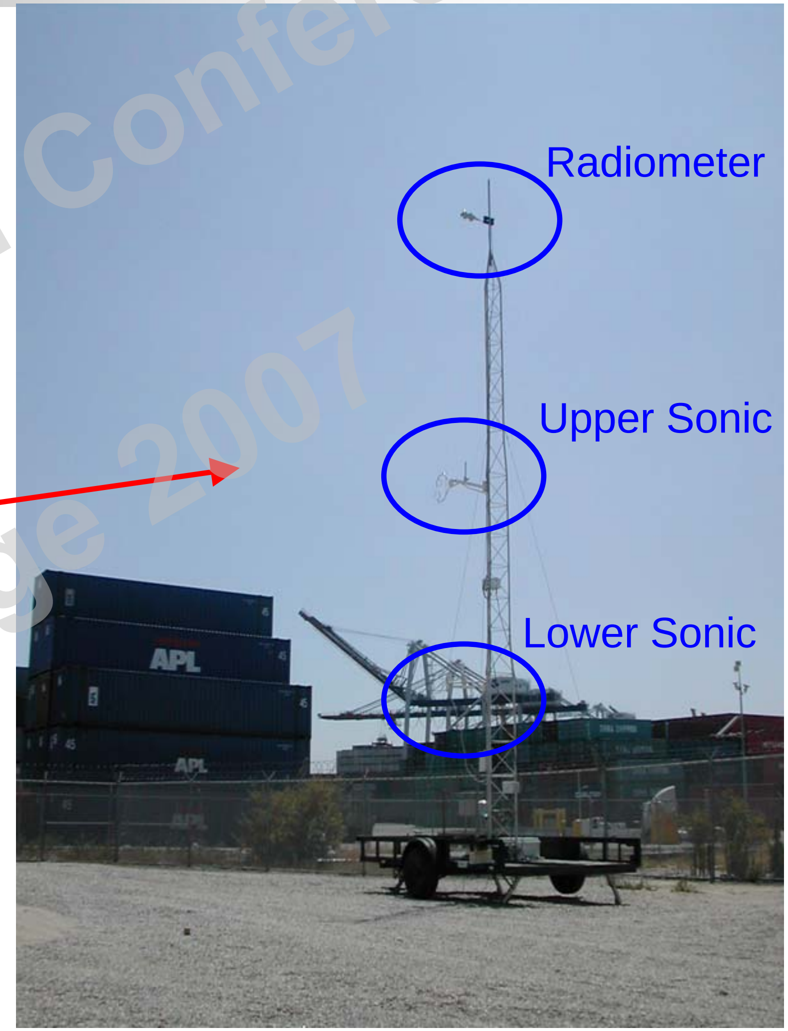
Remarks on using Met Models

- Can provide estimates of u_*, and σ_w
- Heat flux and boundary layer heights are unreliable
- Need tuning with moisture parameter and other surface parameters

Using Urban Measurements

- Make measurements of mean winds, temperature, temperature fluctuations, at one or two levels on a tower
- Use M-O similarity to estimate surface friction velocity, M-O length, and standard deviations of turbulent velocities

Wilmington Instrumentation



VTMX Instrumentation

Stable Conditions

One level of wind: Assume θ_* is constant (Venkatram, 1980)

$$u_* = C_D u(z_r)\left\{\frac{1}{2} + \frac{1}{2}\left[1 - \left(\frac{2u_0}{C_D^{1/2} u}\right)^2\right]^{1/2}\right\}$$

$$\theta_* = 0.5\sigma_T$$

$$\sigma_w = 1.6u_*$$

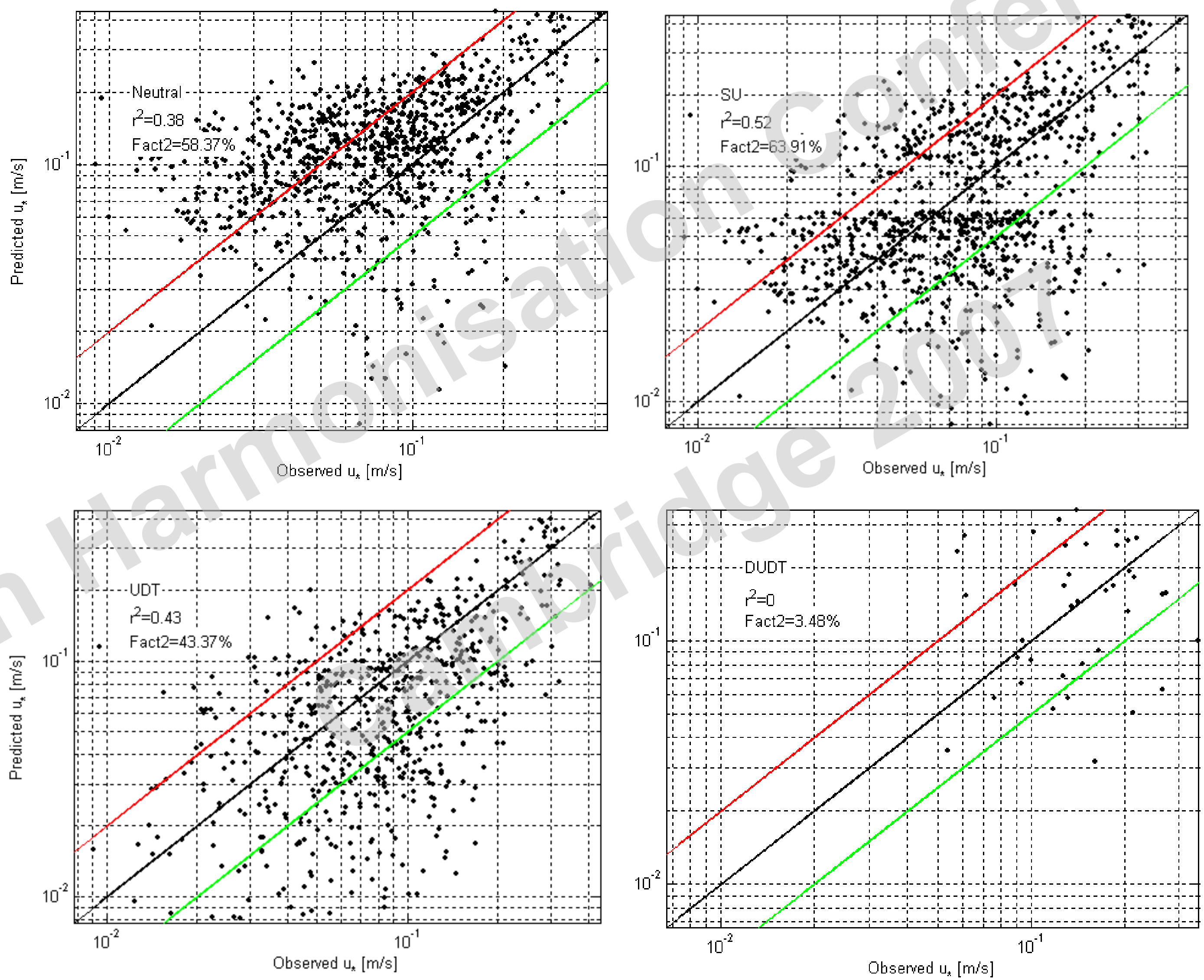
and

$$\sigma_v = 1.9u_*$$

Two levels of temperature: Bulk Richardson number (Irwin and Binkowski, 1980)

Results-Stable Conditions

Site: Wilmington, CA (Los Angeles Metropolitan Area)



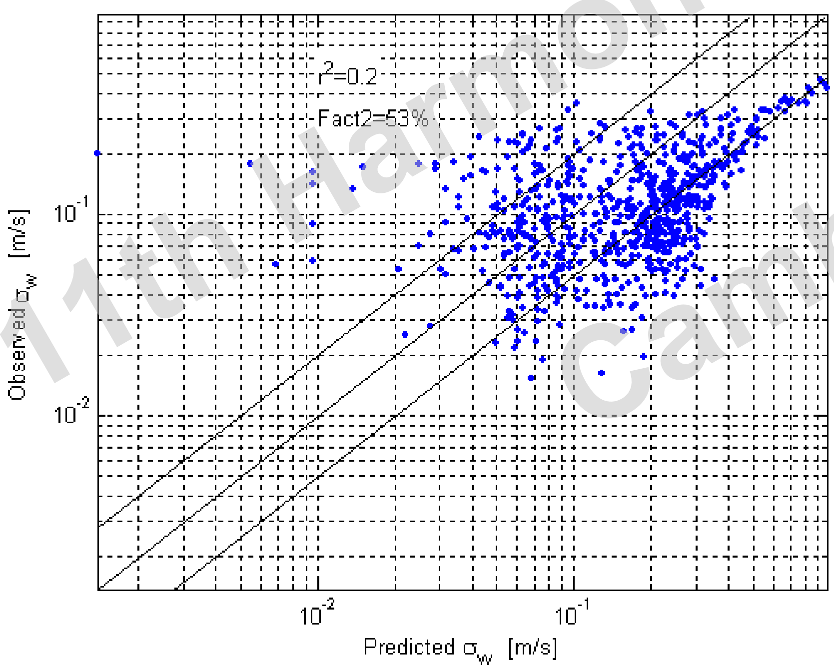
Results-Stable Conditions

$$u_* = C_D u(z_r)\left\{\frac{1}{2}+\frac{1}{2}\left[1-\left(\frac{2u_0}{C_D^{1/2}u}\right)^2\right]^{1/2}\right\}$$

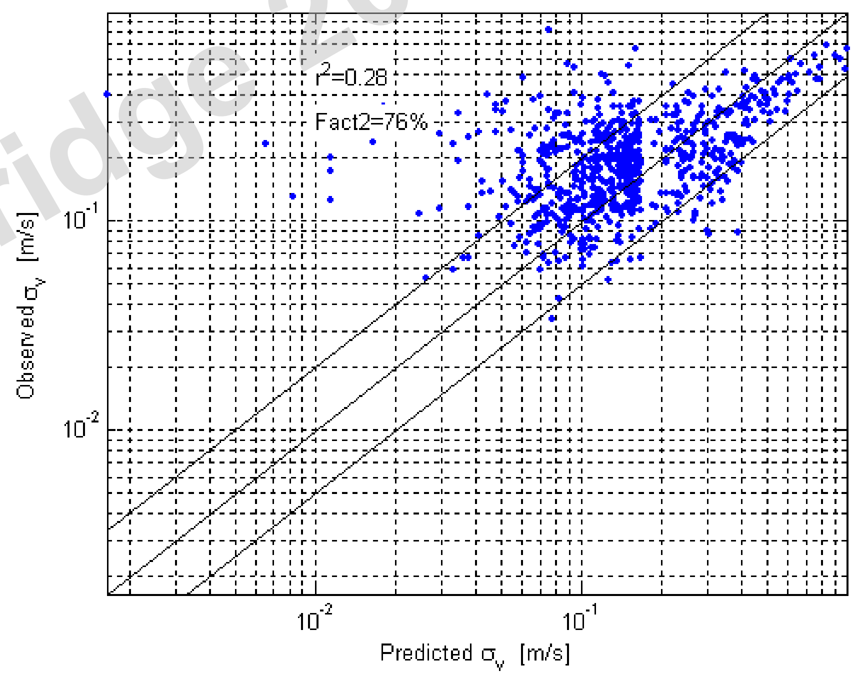
$$\sigma_w = 1.6u_*$$

$$\sigma_v = 1.9u_*$$

Wilmington: SU Observed vs. predicted σ_w on u_* with θ_* on σ_θ - Stable



Wilmington: SU Observed vs. predicted σ_v with θ_* constant - Stable



Unstable Conditions

$$Q_0 = \left(\frac{\sigma_T}{0.95}\right)^{3/2}\left(\frac{g\kappa z_r}{T_0}\right)^{1/2}$$

$$\sigma_w = \left(\sigma_{ws}^3 + \sigma_{wc}^3\right)^{1/3}$$

$$\sigma_{ws} = 1.3u_*$$

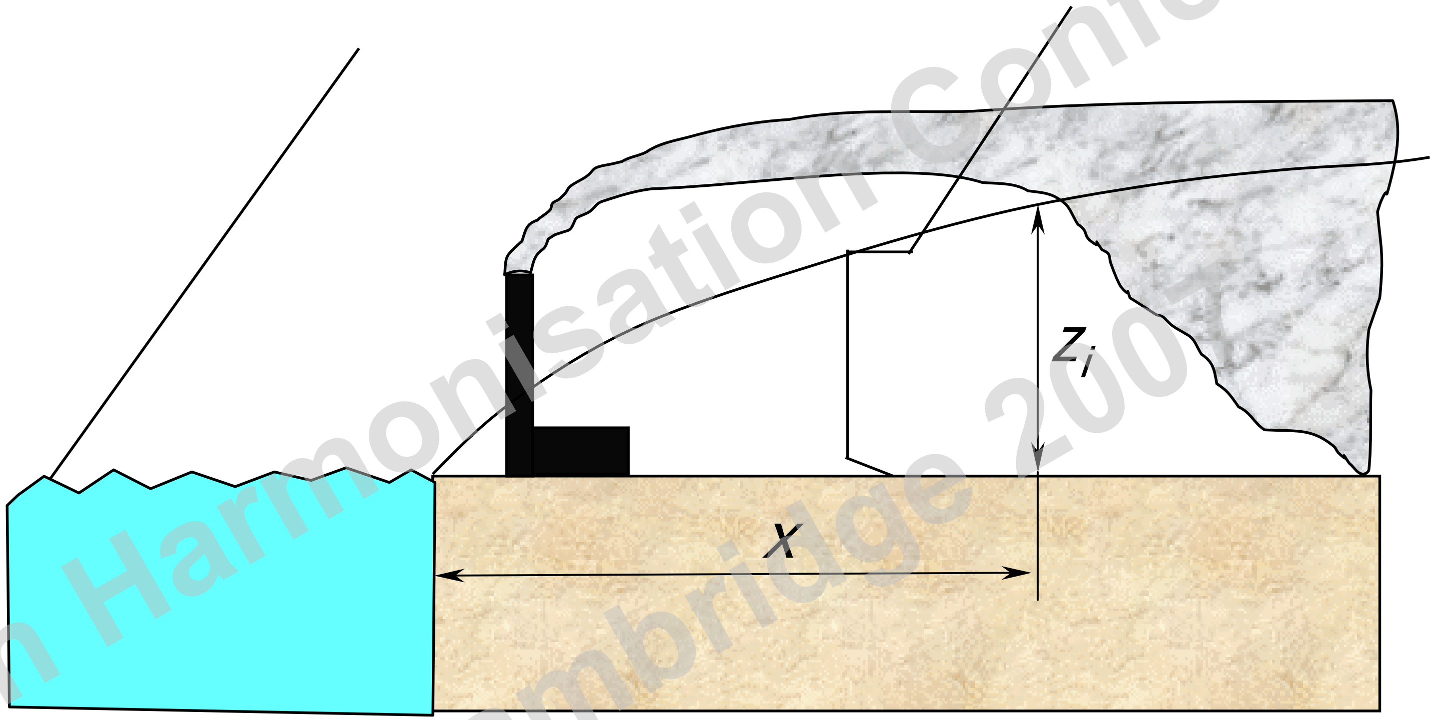
$$\sigma_{wc} = 1.3\left(\frac{g}{T_0}Q_0 z_r\right)^{1/3} \quad \text{for } z_r \le 0.1z_i$$

$$= 0.6w_* \quad \text{for } z_r \ge 0.1z_i$$

where the convective velocity scale w_* is

$$w_* = \left(\frac{g}{T_0}Q_0 z_i\right)^{1/3}$$

Wilmington-Shoreline Meteorology

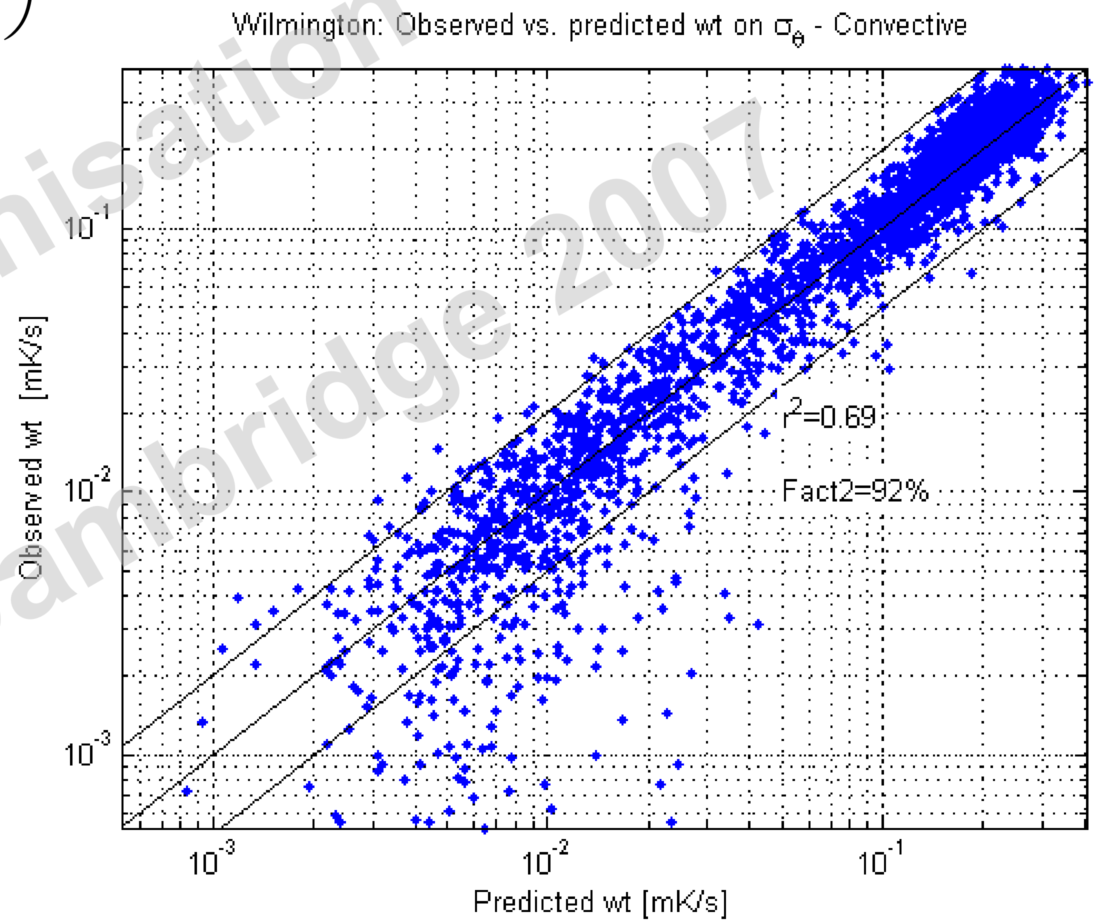


$$z_{\mathrm{i}} = a\left(\frac{Q_{\mathrm{o}}(x + x_{\mathrm{o}})}{U\gamma}\right)^{1/2}$$

$$w_* = Q_0^{1/2}\left(\frac{g}{T_0}\right)^{1/3}\left(\frac{\alpha(x + x_0)}{U\gamma}\right)^{1/6}$$

Results-Unstable Conditions

$$Q_0 = \left(\frac{\sigma_T}{0.95}\right)^{3/2}\left(\frac{g\kappa z_r}{T_0}\right)^{1/2}$$



Results-Unstable Conditions

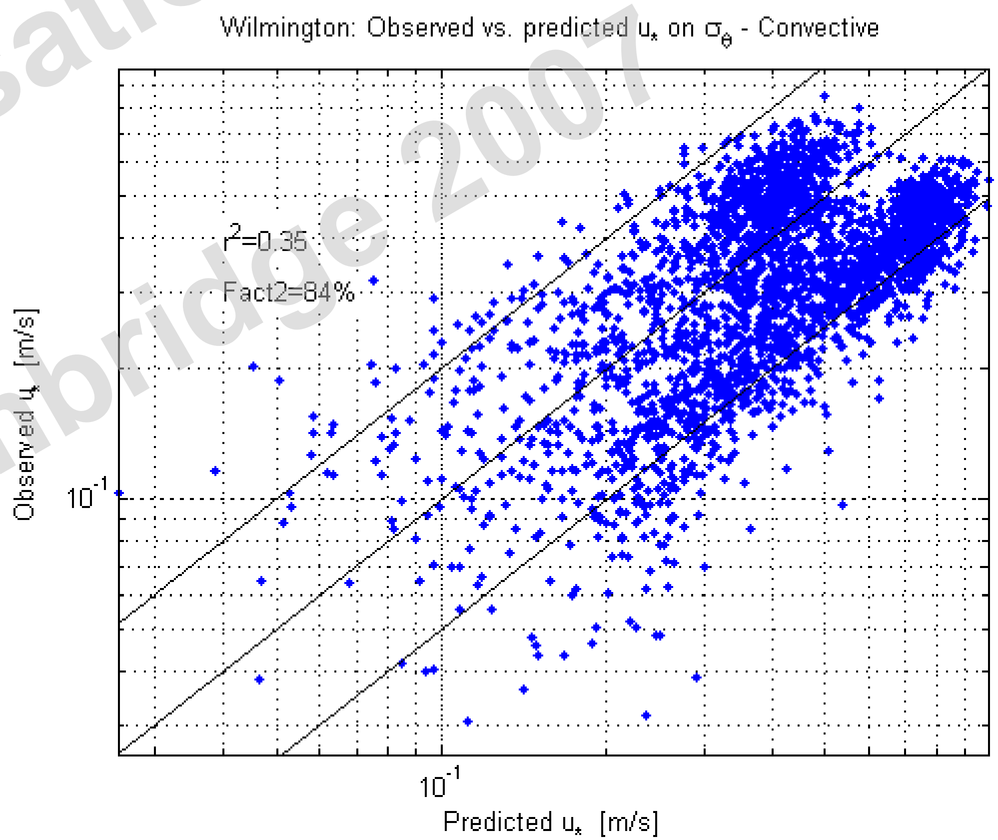
$$u_* = \kappa u \frac{1 + d_1 \ln\left(1 + d_2 d_3\right)}{\ln\left(1/r_h\right)}$$

$$r_h = \frac{z_0}{z_r - d}$$

$$d_1 = \begin{cases} 0.128 + 0.005\ln(r_h) & \text{for } r_h \le 0 \\ 0.107 & \text{otherwise} \end{cases}$$

$$d_2 = 1.95 + 32.6 r_h^{0.45}$$

$$d_3 = \frac{Q_0 \kappa g \left(z_r - d\right)}{T_0}$$



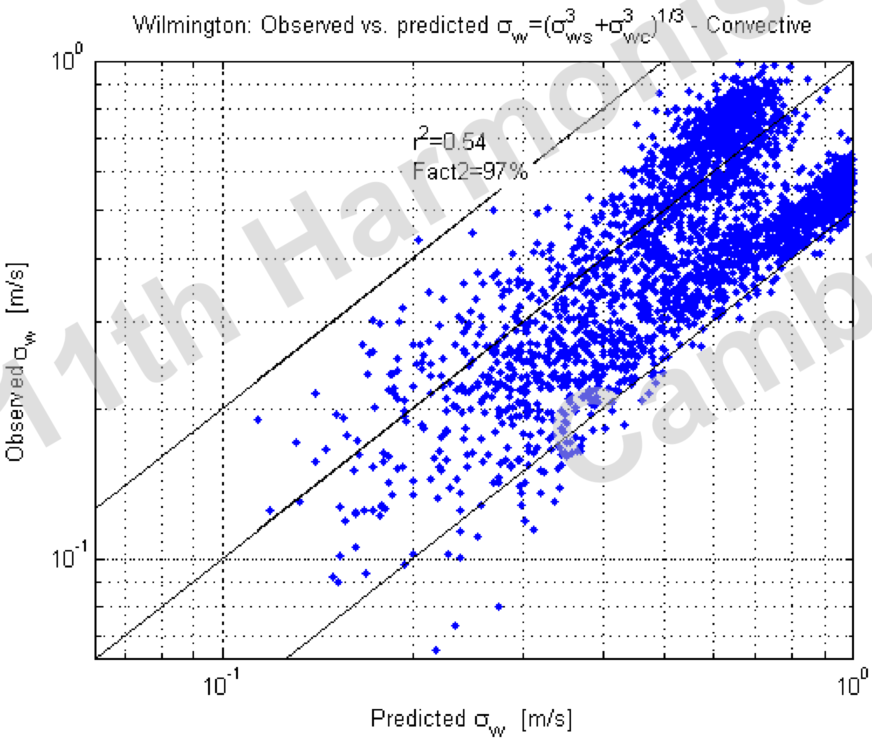
Results-Unstable Conditions

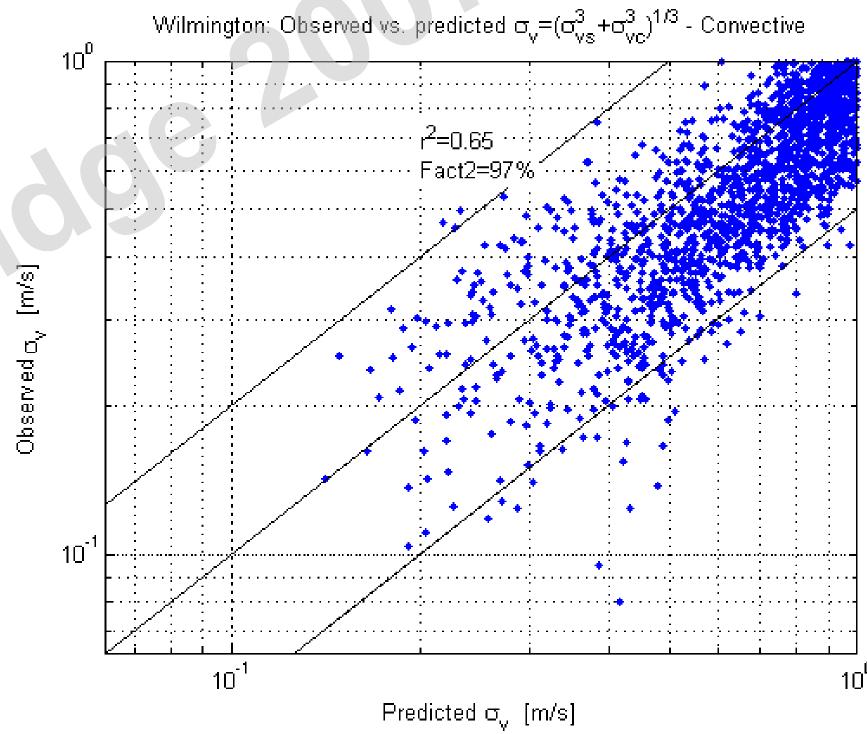
$$\sigma_{ws} = 1.3u_*$$

$$\sigma_{wc} = 1.3\left(\frac{g}{T_0}Q_0 z_r\right)^{1/3}$$

$$\sigma_{vs} = 1.9u_*$$

$$\sigma_{vc} = 0.6w_*$$





Conclusions

- Comprehensive and IBL models provide reasonable estimates of urban parameters. However, calculation of heat flux is uncertain.
  - Moisture parameter dominates heat flux calculation
- One or two level measurements of winds and σ_T can be used to estimate urban parameters. More testing is required.
  - Two levels can increase errors

Acknowledgements

Sponsors:

California Air Resources Board, California Energy Commission, National Science Foundation

Students:

Jing Yuan, Tao Zhan

Postdocs:

Sang-Mi Lee

Colleagues:

David Pankratz, Vlad Isakov