DEVELOPMENT AND APPLICATION OF METHODS TO ESTIMATE THE AIR QUALITY IMPACT OF URBAN EMISSIONS OVER MULTIPLE LENGTH SCALES

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- Motivation
- Lagrangian dispersion model
- Species age equation
- Some results
- Conclusions
- Speculations on the urban canopy layer

Motivation

Muliti-scale models generally combine results from models that apply at different scales:

- Regional scale models – Grid models, CMAQ
- Urban scale models – CIT, CMAQ
- Neighborhood scale models –ADMS, AERMOD, OSPM

Grid models

Require large computational resources if more than a few days are simulated, and sensitivity studies are required. Large number of inputs make them prone to errors.

Urban "Background" Model

Simple models, such as Urban Background Model (UBM, Berkowicz) and DAUMOD, (Mizzeo and Venegas, 1991), have been used with some success

- Steady state model
- Chemistry treatment is uncertain

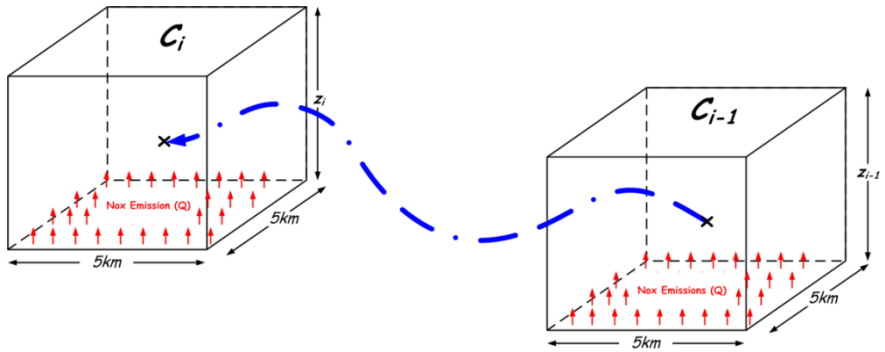
Lagrangian trajectory model can treat unsteady wind fields, and can include chemistry

Formulation
Receptor Oriented

$$\frac{d(z_i C)}{dt} = q_i(\vec{r})$$

$$\mathrm{C_i} = C_{i-1} \min\left(\frac{z_{i-1}}{z_i}, 1\right) + \frac{\Delta m_i}{z_i}$$

$$\Delta m_i = q_i(\vec{r})\Delta t$$



In the last time step

$$\Delta C_i = \sqrt{\frac{2}{\pi}} \frac{q}{\sigma_w} \ln\left(1 + \frac{\sigma_w \Delta t}{h}\right)$$

Meteorological inputs from AERMET surface files

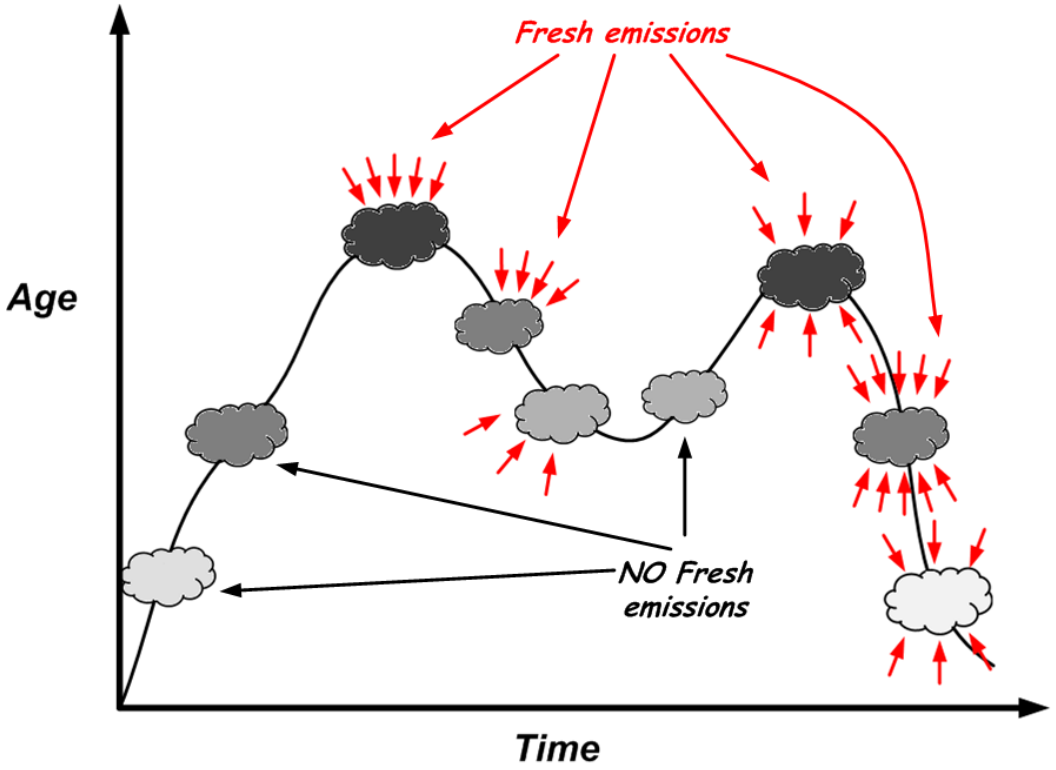
Species 'Age' Equation

$$\frac{d\phi}{dt} = \mathrm{C}(\vec{r}, \mathrm{t})$$

$$\phi = \mathrm{A}(\vec{r}, \mathrm{t})\ \mathrm{C}(\vec{r}, \mathrm{t})$$

Reduces to

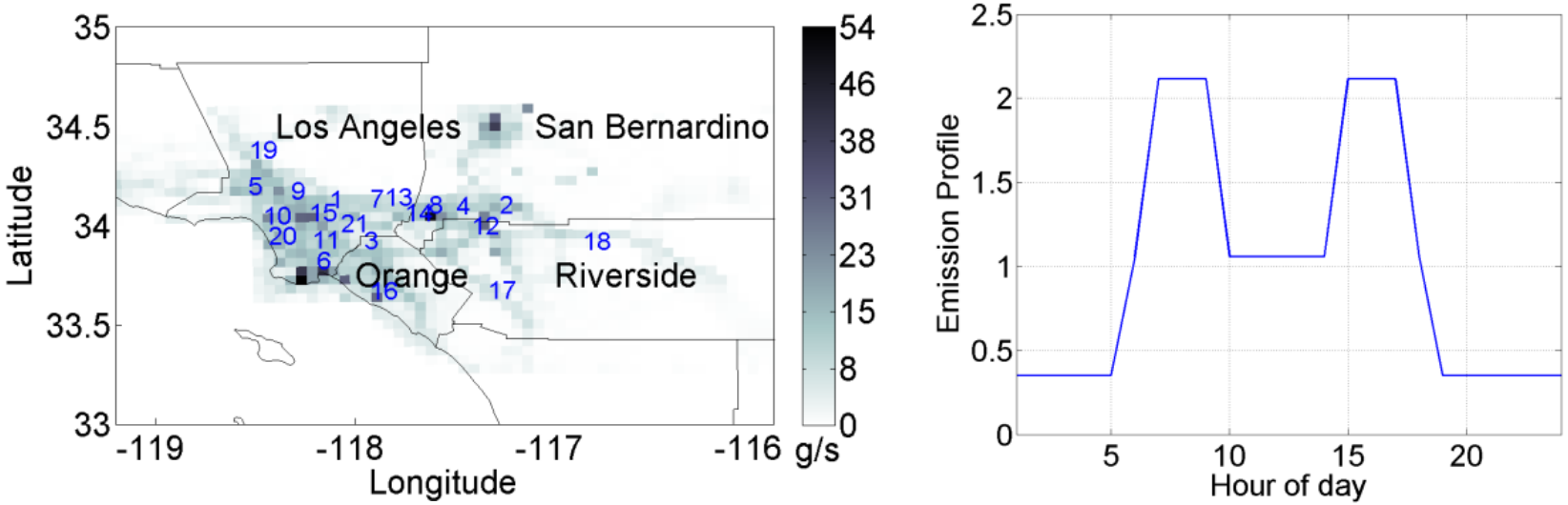
$$A_i = A_{i-1}\left(1 - \frac{\Delta m_i}{m_i}\right) + \Delta t\left(1 - \frac{1}{2}\frac{\Delta m_i}{m_i}\right)$$



Approach

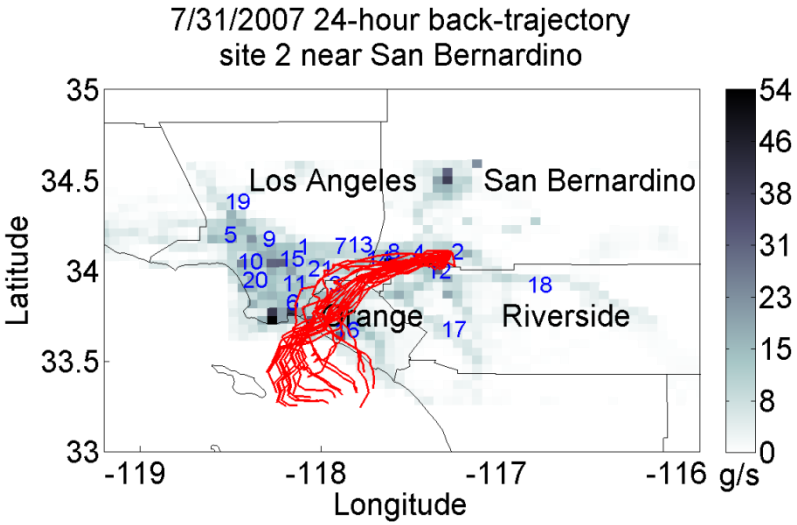
- Concentrations of NO_x are calculated assuming no chemistry
- Chemistry performed in a box over a time corresponding to the maximum age of species in the box
  - Carbon Bond IV used to perform chemistry
  - $\frac{NO_x}{VOC}$ ratio assumed to be constant=1/6
  - Background ozone = 20 ppb
  - Background VOC= 40 ppb
  - VOC speciated using LA profile

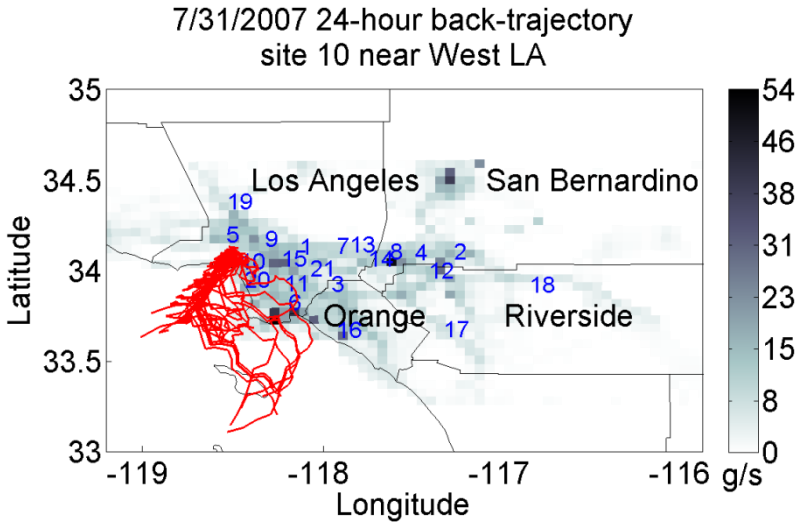
Application



Gridded NO_x emissions and monitoring stations located in the South Coast Air Basin, Los Angeles. The right panel shows the assumed temporal profile of NO_x emissions

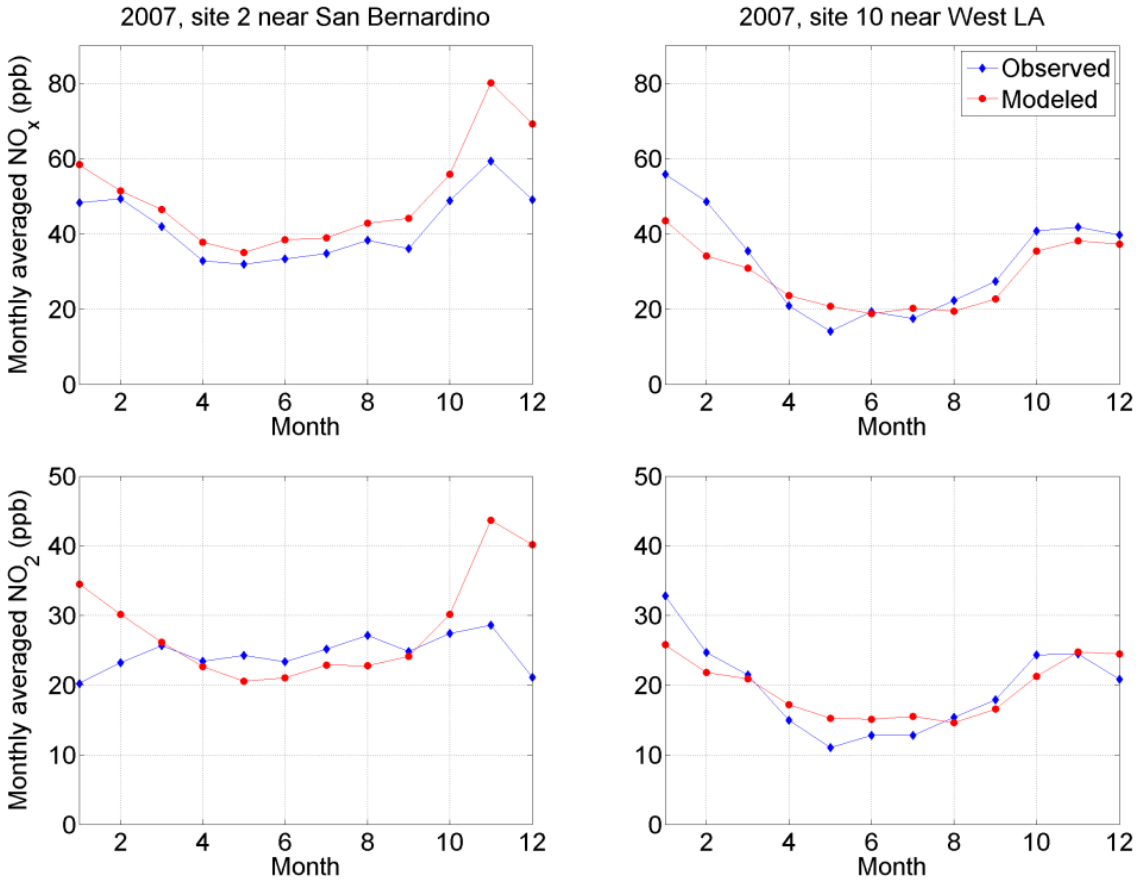
Back Trajectory Calculation





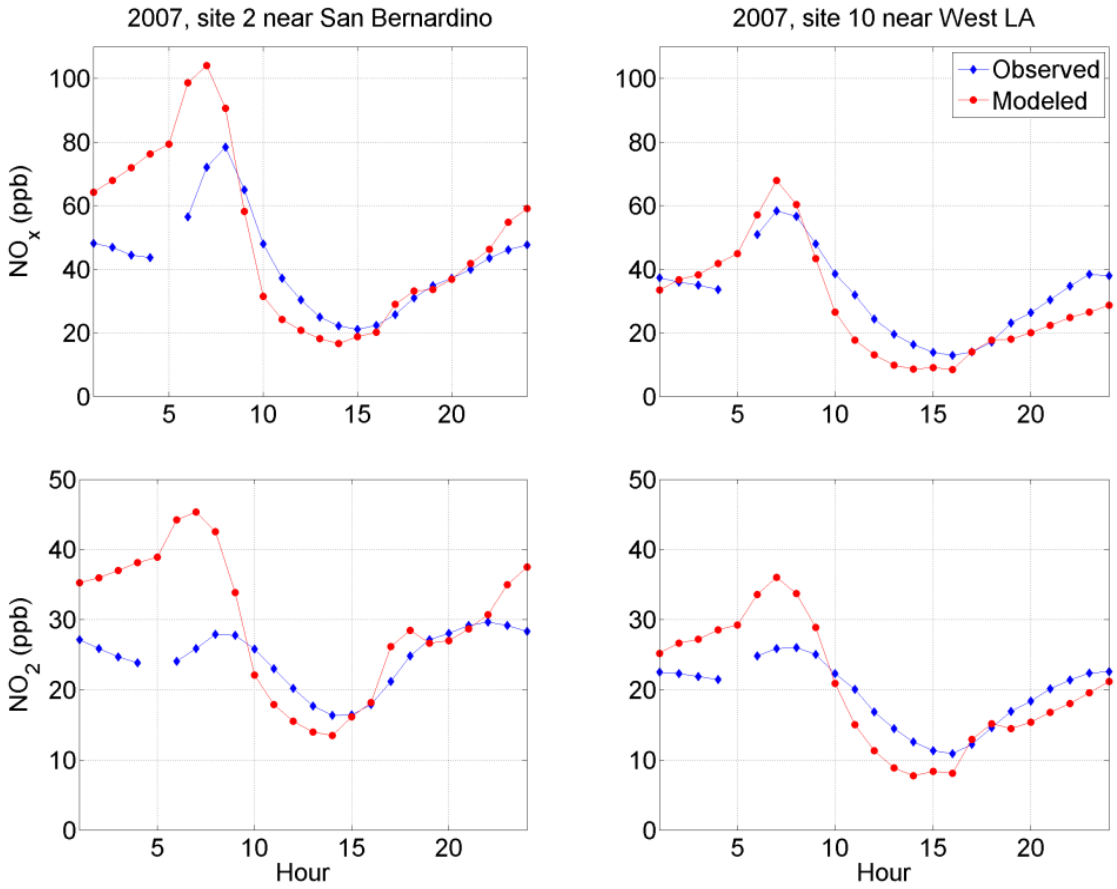
Back trajectory is calculated using the nearest meteorological station in the SoCAB.

Monthly Variation



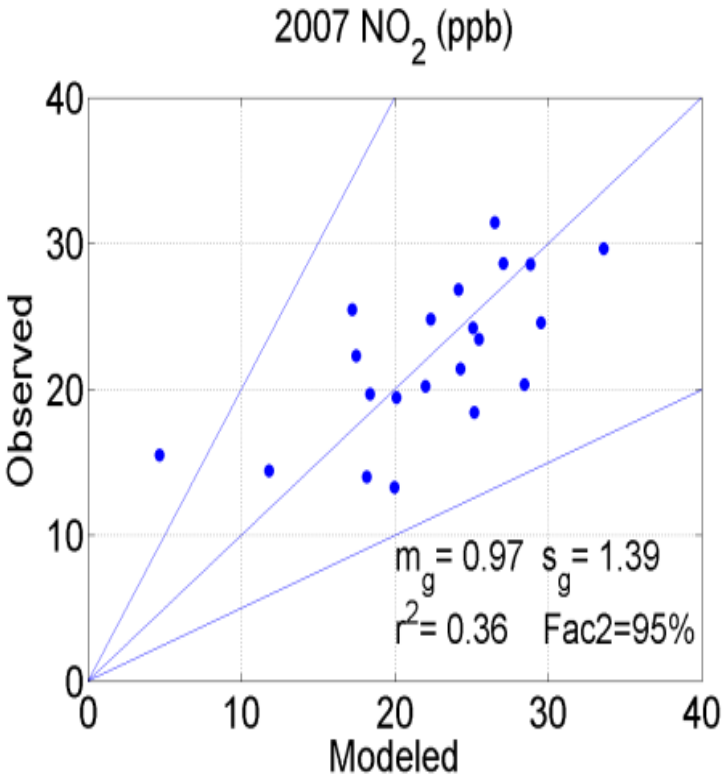
. Monthly averaged NO_x and NO_2 concentrations compared with observations at two sites in the SoCAB

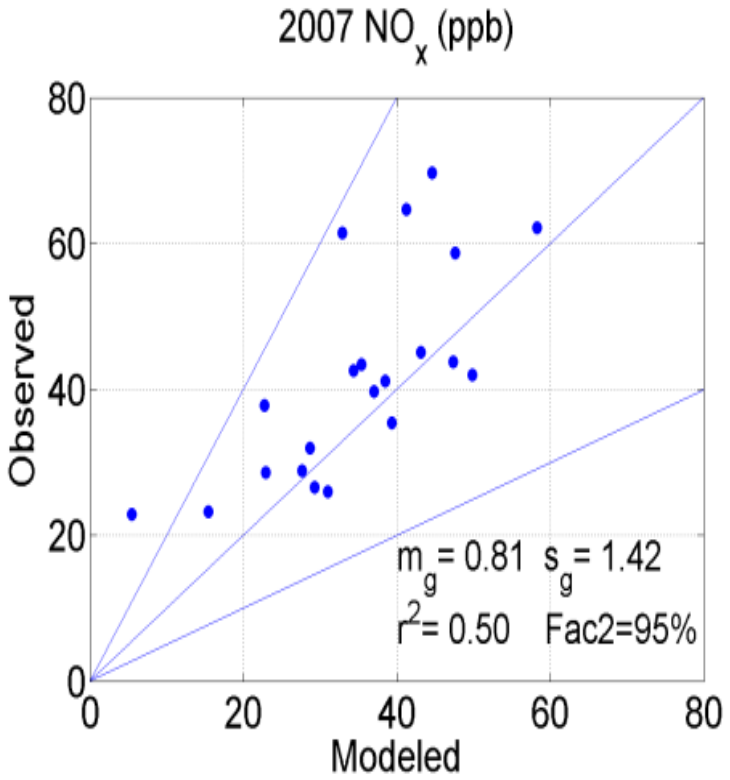
Hourly Variation



Averaged daily variation of NO_x and NO_2 compared with observations at two sites in the SoCAB

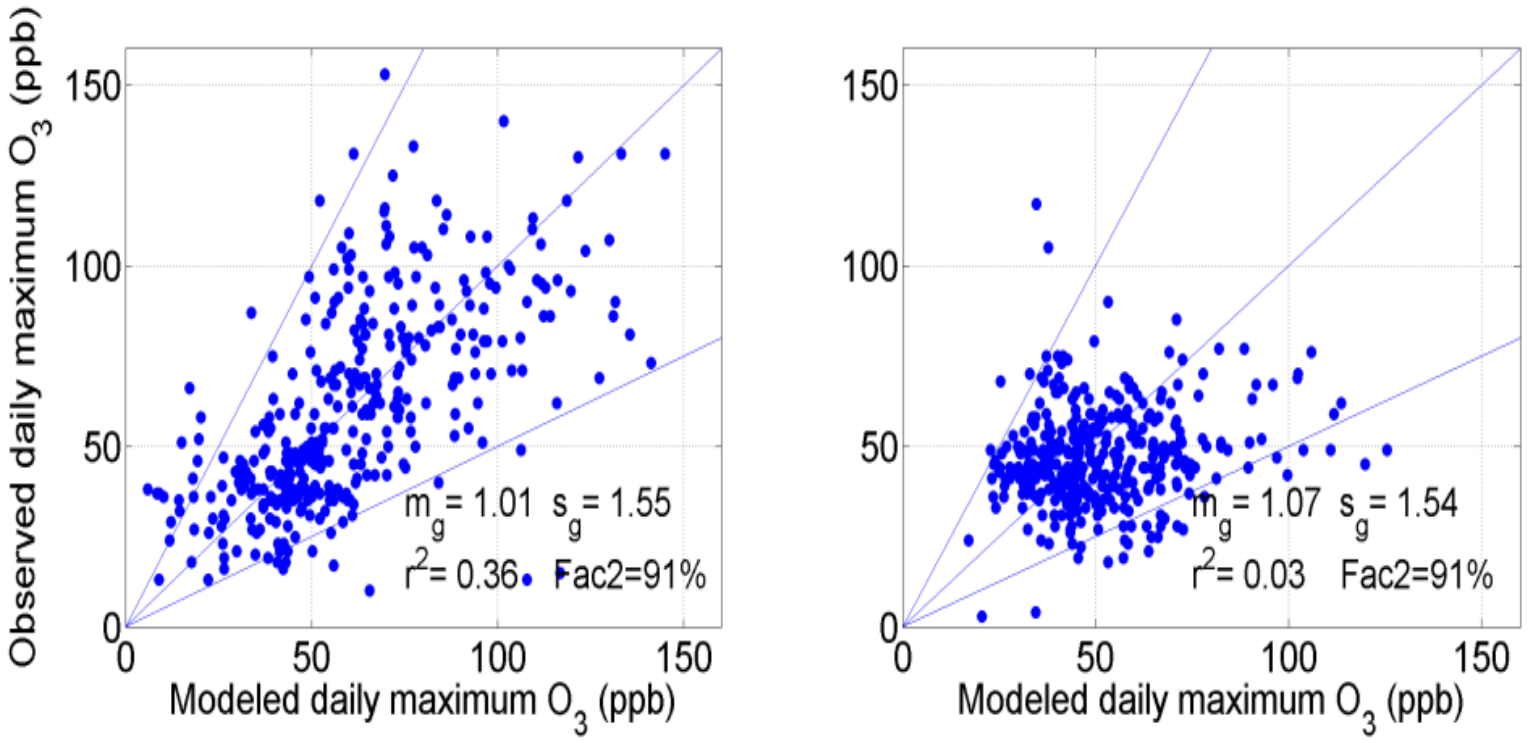
Spatial Variation Annual NO_2 and NO_x





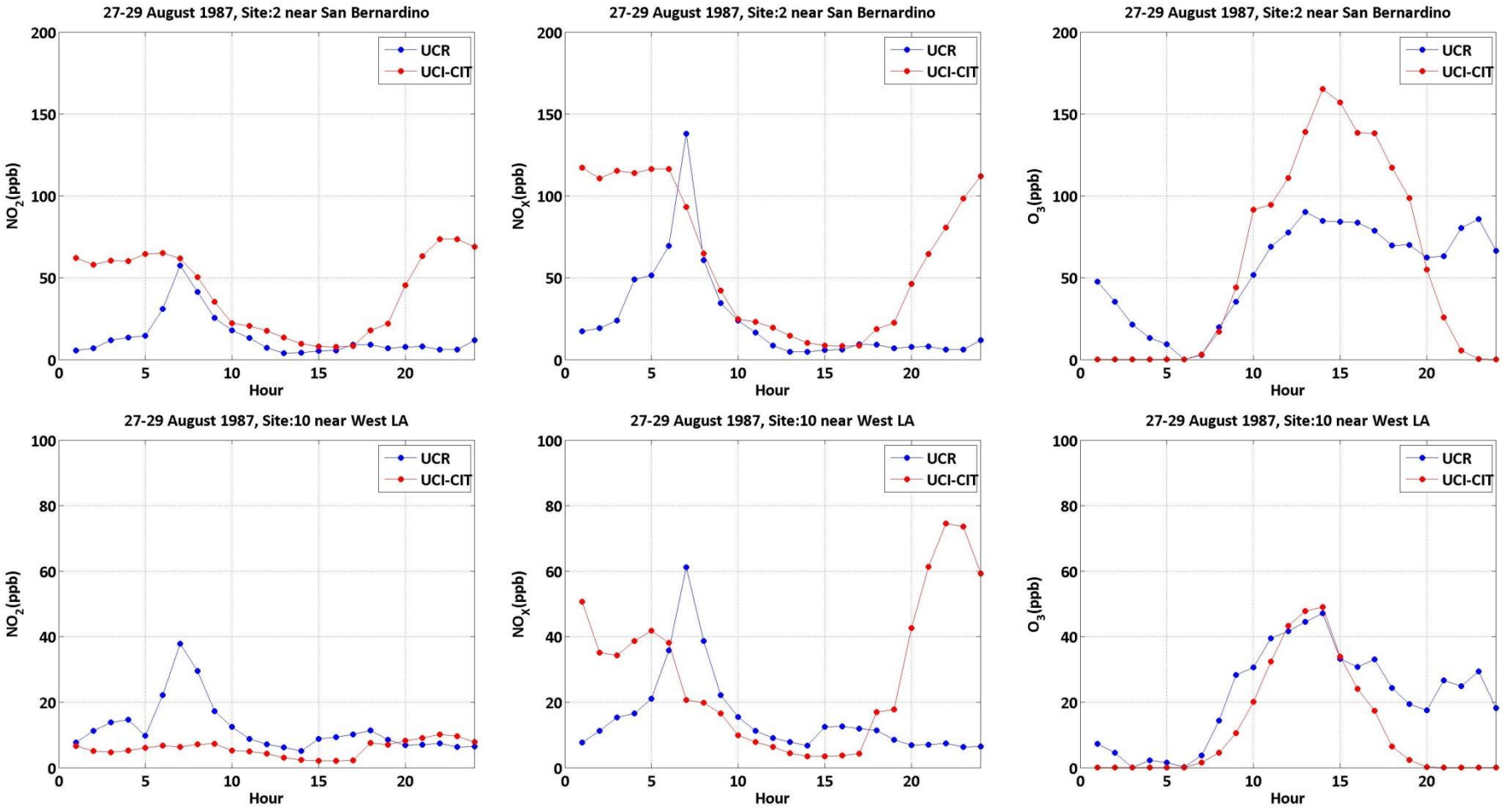
Comparison of modelled and measured annually averaged NO_2 and NO_x concentrations at 21 sites in the SoCAB

Results- Ozone



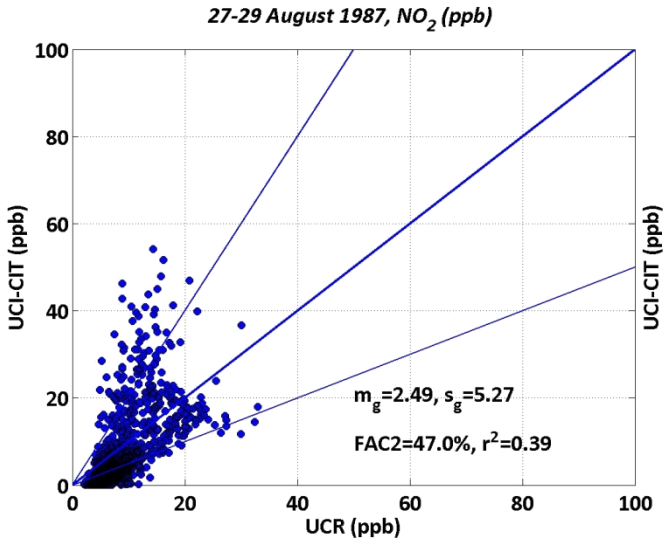
. Daily maximum ozone concentrations compared with observations at two sites in the SoCAB

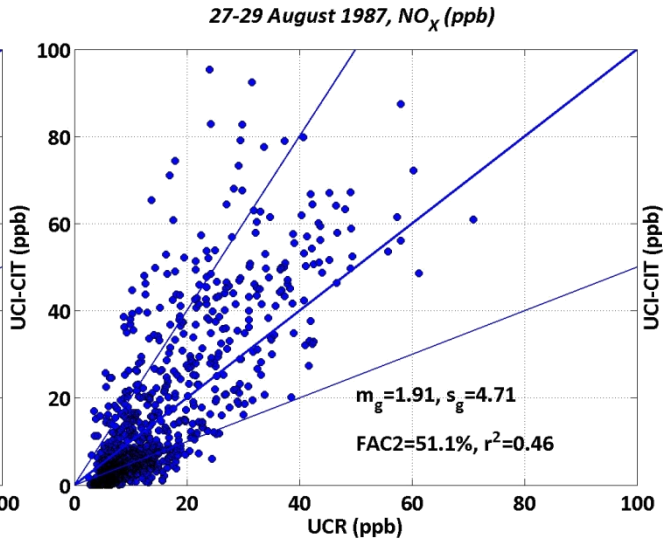
UCR vs. UCI-CIT Results

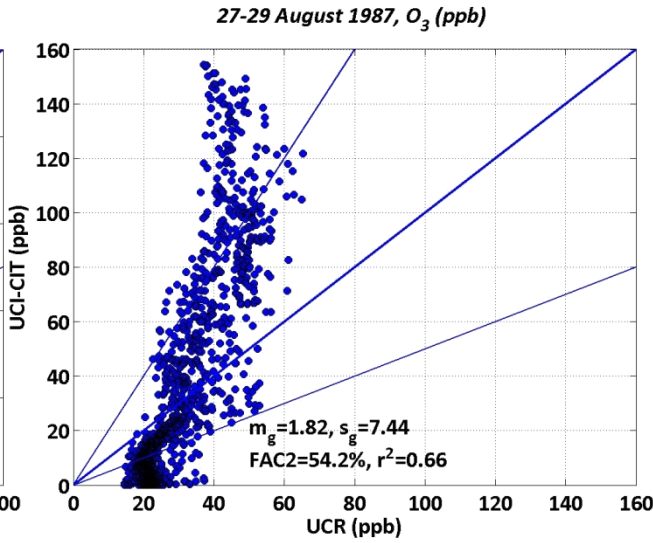


Comparison of UCR model and UCI-CIT daily averaged NO_x, NO_2, and O_3 concentration predictions at two different sites in the SoCAB

UCR vs. UCI-CIT Results





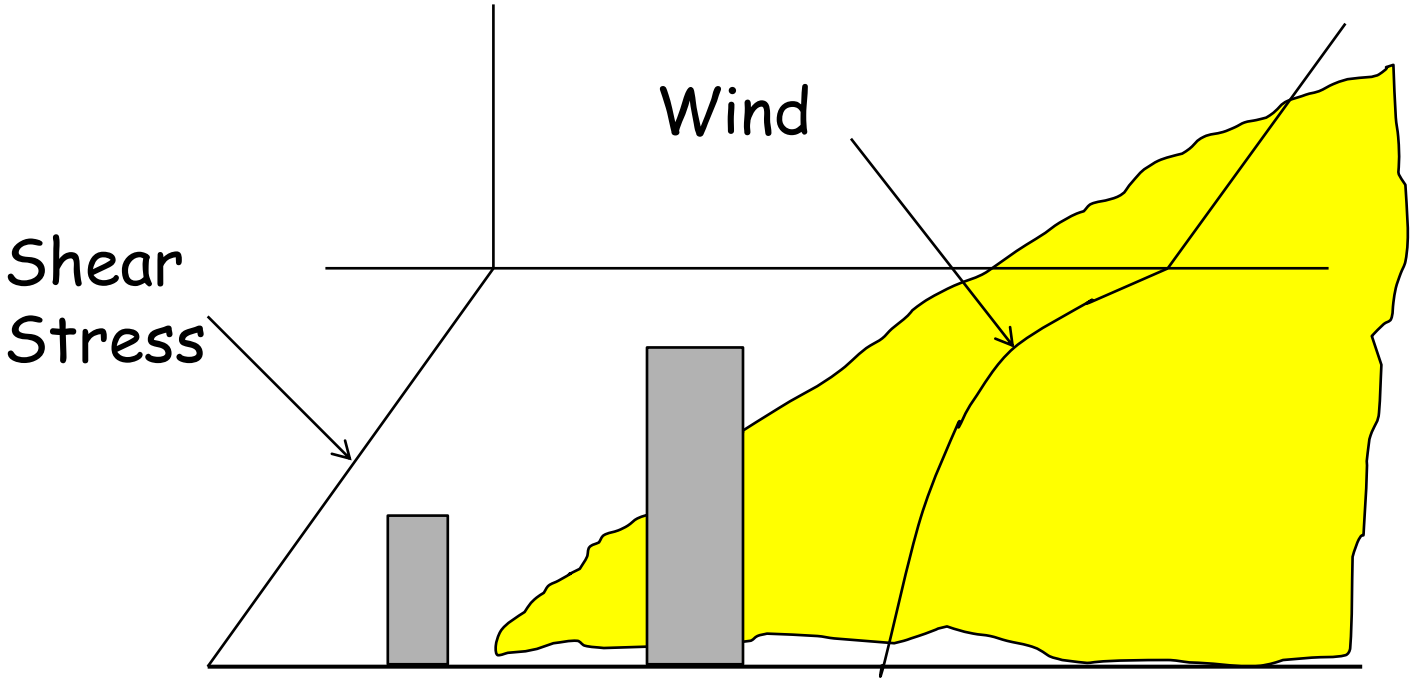


Comparison of UCR model and UCI-CIT 72Hr averaged NO_2, NO_x , and O_3 concentrations at **994** sites in the SoCAB

Conclusions

- A simple Lagrangian model can be used to estimate background concentrations of NO, NO_2, and O_3 in an urban area
- The model can provide hourly concentrations of these species over time periods of a year
- The model achieves computational efficiency by separating transport and chemistry using the concept of species age
- Model provides adequate descriptions of the spatial and temporal behaviour of NO_x and NO_2 measurements made in SoCAB during 2007
- Model estimates of maximum hourly ozone concentrations are unbiased relative to observations but the 95% confidence interval ($\approx s_g^2$) of the ratios of observed to estimated concentrations is over a factor of two.

Urban Canopy Model



Urban Canopy Model

Model dispersion in canopy layer with modified wind speed and eddy diffusivity profiles

$$U\frac{\partial C}{\partial x} = \frac{\partial}{\partial z}\left(K\frac{\partial C}{\partial z}\right)$$

$$U = U_H \exp\left(-\alpha\left(1-\frac{z}{H}\right)\right) \qquad \alpha = \left[\frac{H^2}{4l^2}C_D\lambda_f\right]^{\frac{1}{3}}$$

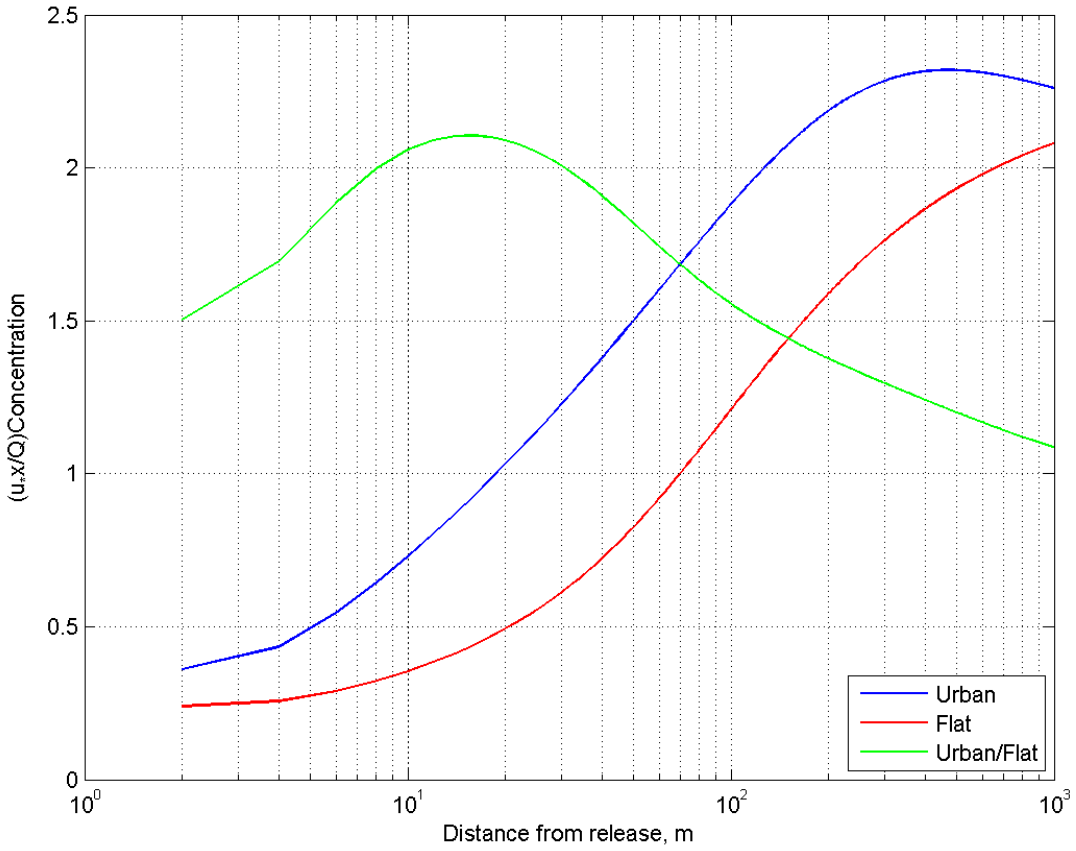
Urban Canopy Model- Eddy Diffusivity

$$K = l^2 \left(\frac{dU}{dz} \right)$$

Matching the shear stress at the top of the canopy layer results in

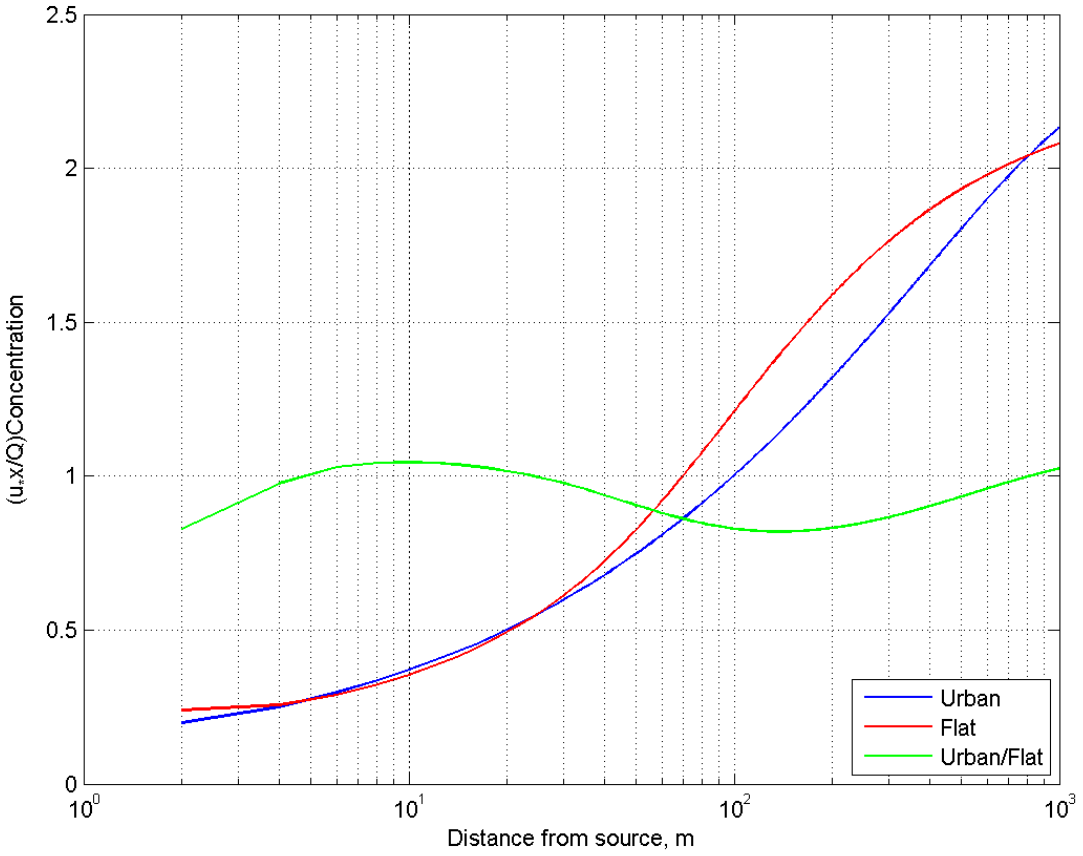
$$l = H \left(\frac{u_*}{U_H} \right)^3 \left(\frac{4}{C_D \lambda_f} \right)$$

Urban/Flat Concentration Ratio



H=10 m, and $\lambda p=\lambda_f=0.2$.

Tall Buildings



H=60 m, and $\lambda_p = \lambda_f = 0.2$.

Tentative Conclusion

Can we treat urban canopy effects by using modified vertical spreads derived from numerical simulations of dispersion within an urban canopy?