UNDERSTANDING AIR POLLUTION

The Past and the Future

Akula Venkatram

- 'Understanding'
- Air pollution problems
  - Acid deposition
  - Urban pollution
- The future

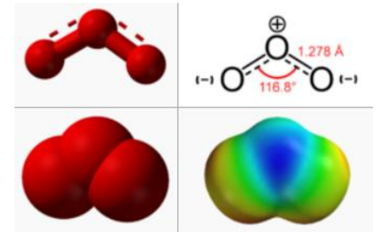
Air Pollution in the News

Empty skies proved that airports cause pollution, say researchers
By Michael McCarthy, Environment Editor and Phil Boucher

Eyja*fjalla*jokull

Islandmountainglacier

Understanding

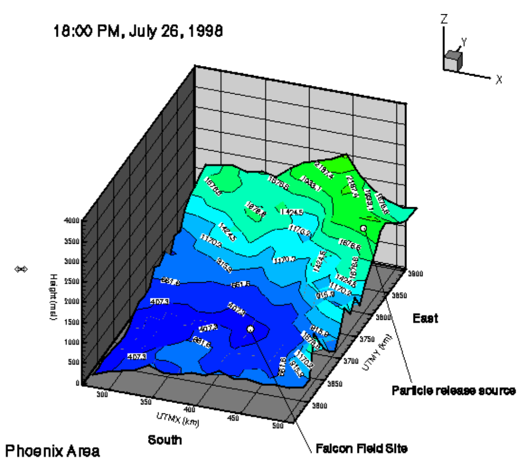


Basic physics and chemistry

Comprehensive or semi-empirical models

Observations

Simulations to formulate mitigation strategies

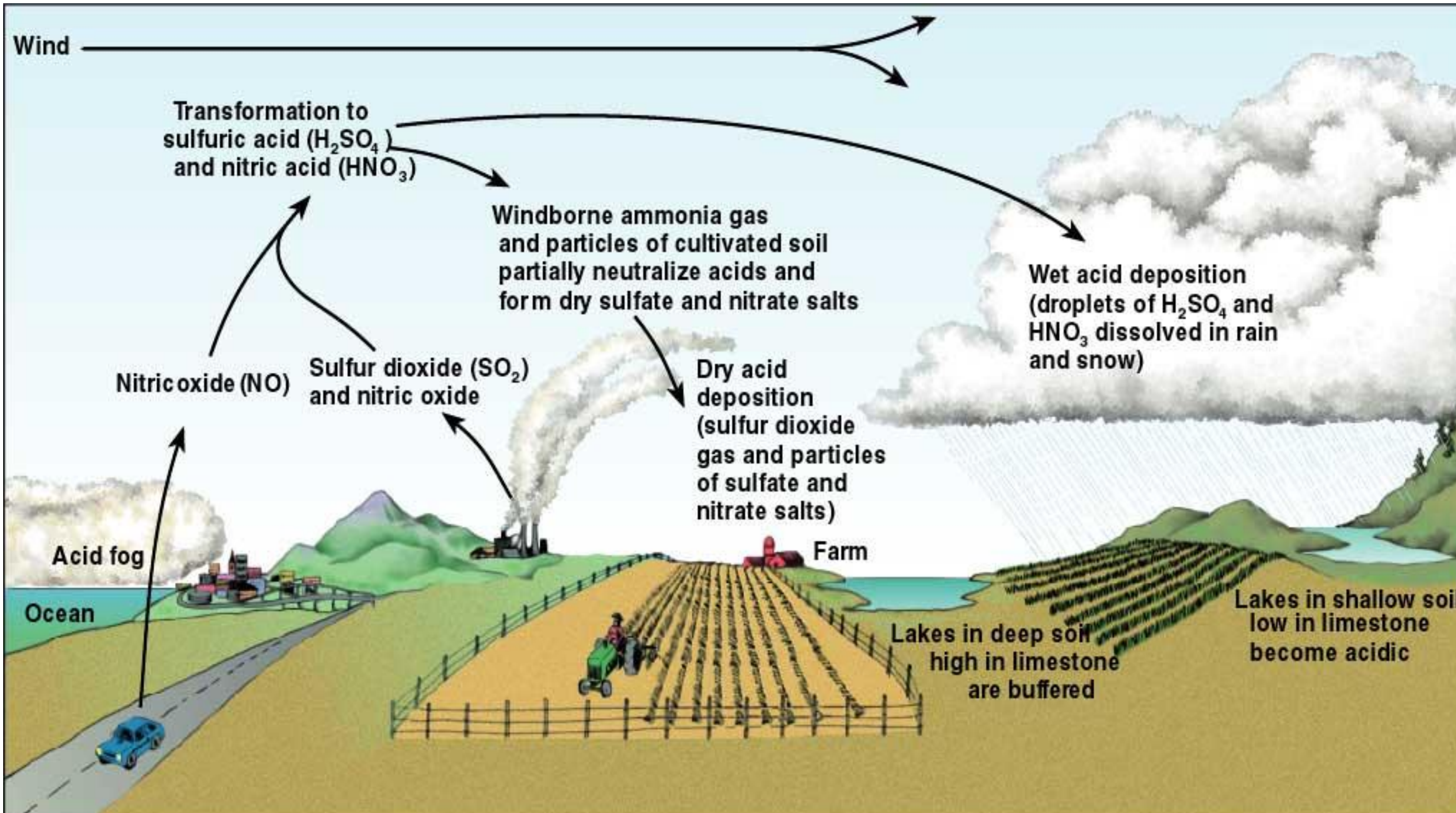


Acid Deposition

- Deposition of acidifying pollutants became a concern in the 1970s
- Acid deposition believed to be damaging lake and forest ecosystems in Scandinavia

WALDSTERBEN !!

Acid Deposition



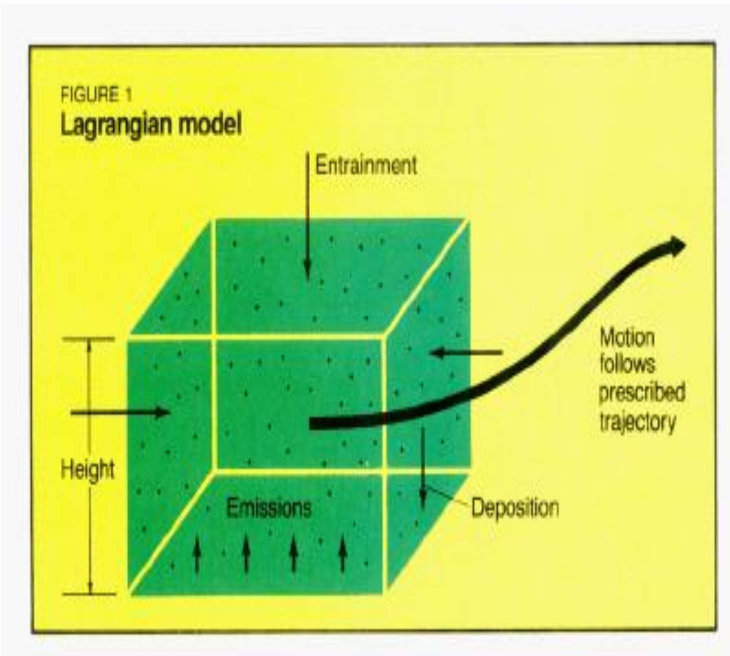
Acid Deposition

The early models were semi-empirical: Lagrangian trajectory models, statistical models for long-term concentrations

- Bolin and Persson, 1975
- Eliassen and Saltbones, 1975
- Fisher, 1975
- Venkatram et al., 1982

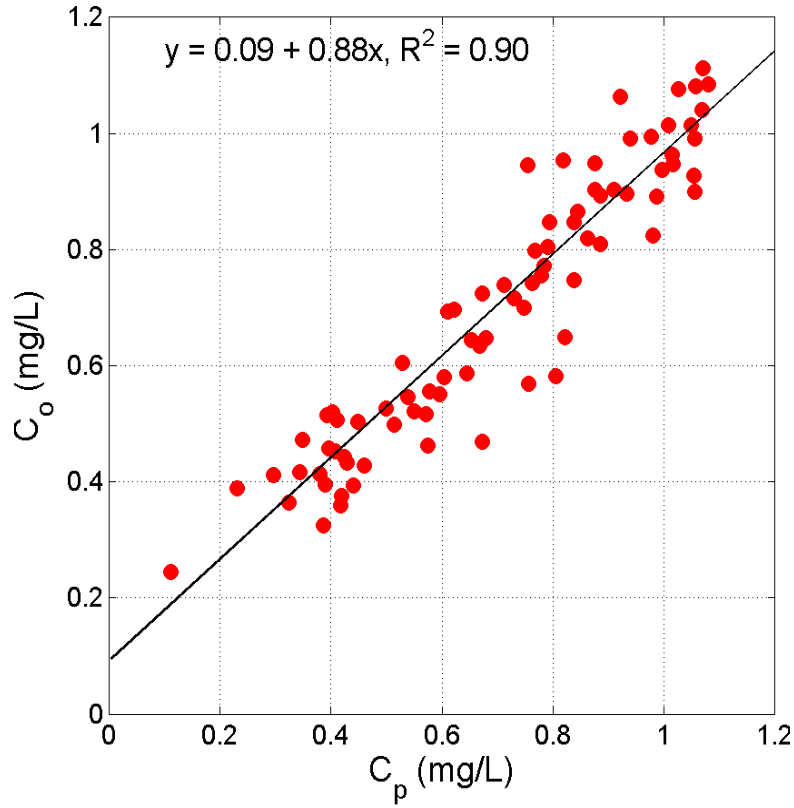
Semi-Empirical Models

- Parameters for chemistry, dry deposition, wet deposition
- Transport modeled using trajectories or 'wind roses'



$$\frac{dp}{dt} = \frac{Q(t)}{h} - \lambda p - kp$$

$$\frac{dq}{dt} = -\bar{\lambda} q + kp$$



Comparison of model predictions with observations of sulfur concentrations in rain averaged over 1982-1985. Venkatram et al. 1990

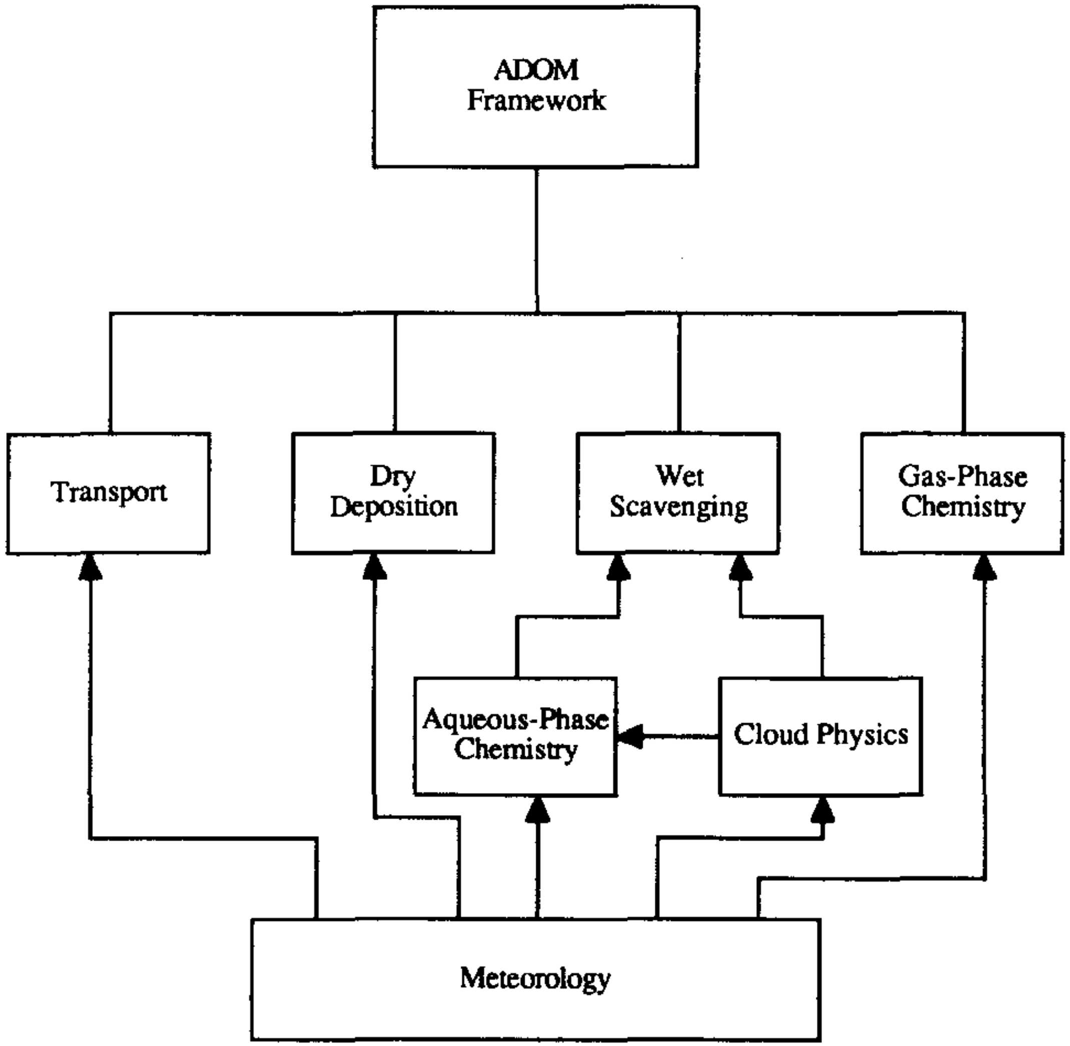
Issues with Semi-empirical Models

- Difficult to incorporate fundamental understanding into parameter values
  - Chemistry is generally simple
  - Transport does not account for wind shear

Comprehensive Models

- Designed to incorporate processes in as much detail as possible
- Designed to serve as numerical surrogates of governing system once it has been evaluated with observations
  - Used to conduct experiments that would be impossible in the real world

Comprehensive Models – Acid Deposition and Oxidant Model



Acid Deposition - Gas Phase Chemistry

$$SO_2 + OH \rightarrow HOSO_2 + O_2 \rightarrow SO_3 + HO_2$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

$$NO_2 + OH \rightarrow HNO_3$$

$$O_3 + h\nu \rightarrow O_2 + O$$
$$O + H_2O \rightarrow 2OH$$

Acid Deposition - Aqueous Phase Chemistry

$$SO_2 + H_2O \Leftrightarrow H_2O.SO_2$$

$$H_2O.SO_2 \Leftrightarrow HSO_3^- + H^+$$

$$HSO_3^- + H_2O_2 + H^+ \rightarrow SO_4^= + 2H^+ + H_2O$$

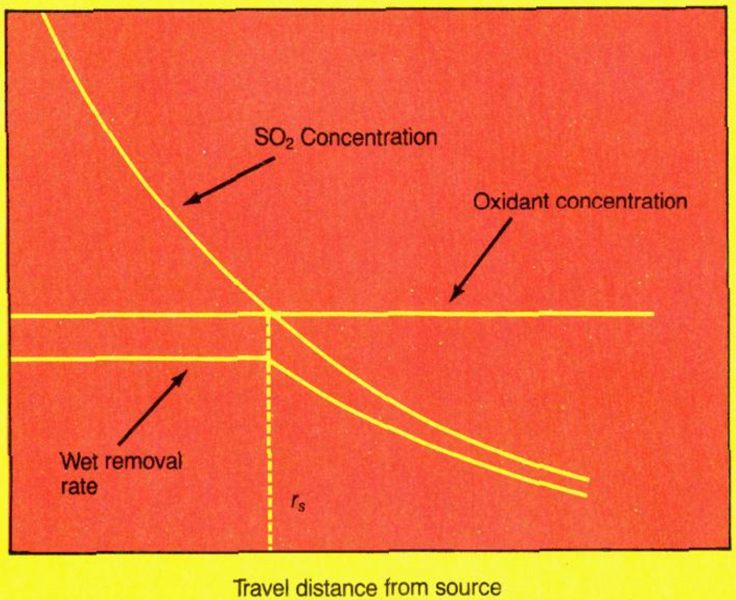
$$SO_2 + H_2O_2 \rightarrow SO_4^= + 2H^+$$

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2$$

Role of H_2O_2

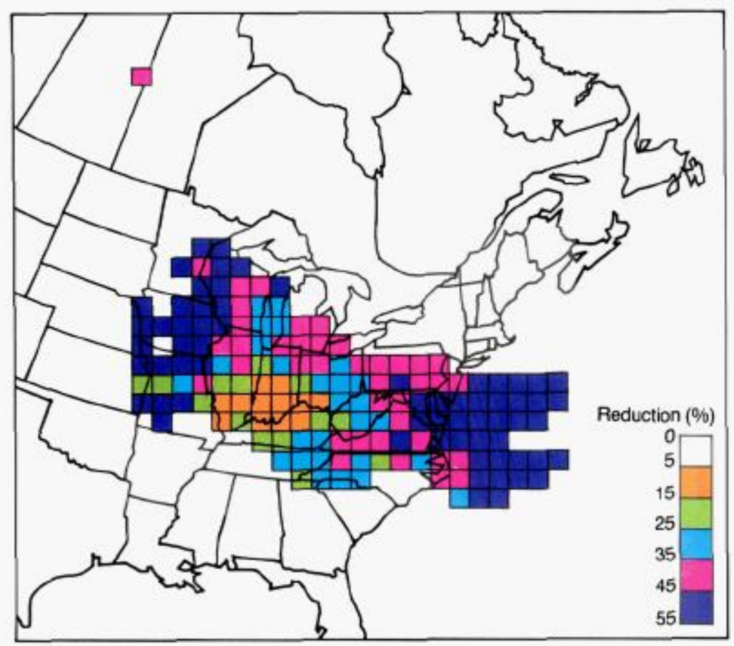
- Hydrogen peroxide oxidizes SO_2 in cloud water: wet removal of SO_2 is more efficient than that suggested by dissolution of SO_2
- Scavenging by rain is limited by the concentration of H_2O_2

FIGURE 3
Wet scavenging during oxidant-limited conditions



r_s = Distance below which oxidant limitation applies.

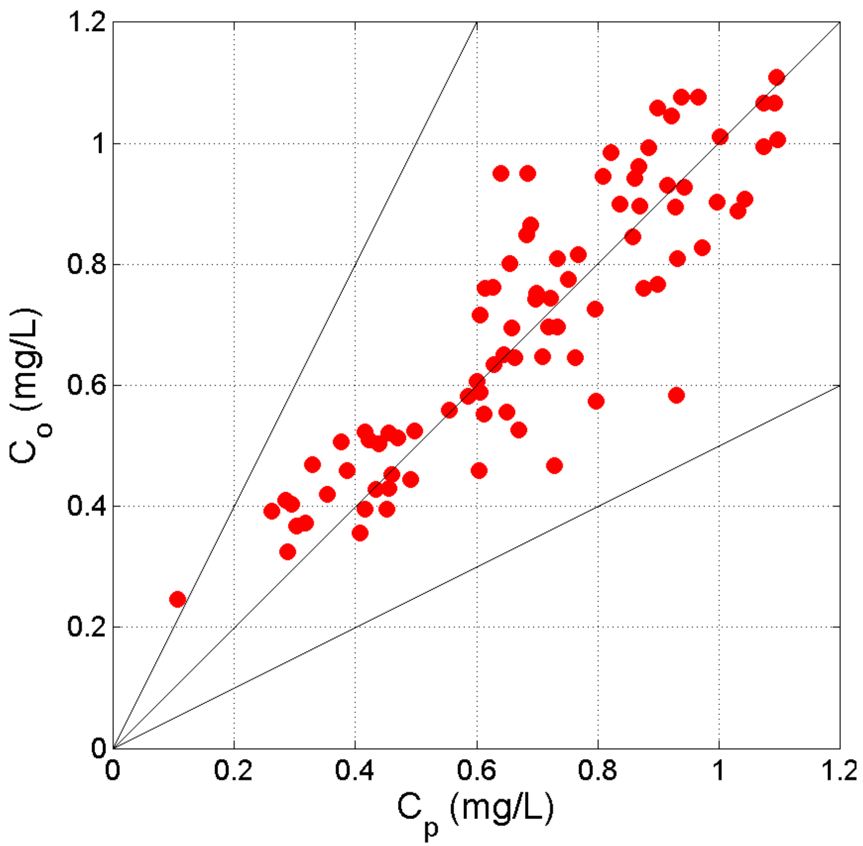
FIGURE 6
Reduction in emissions alters wet deposition[a]



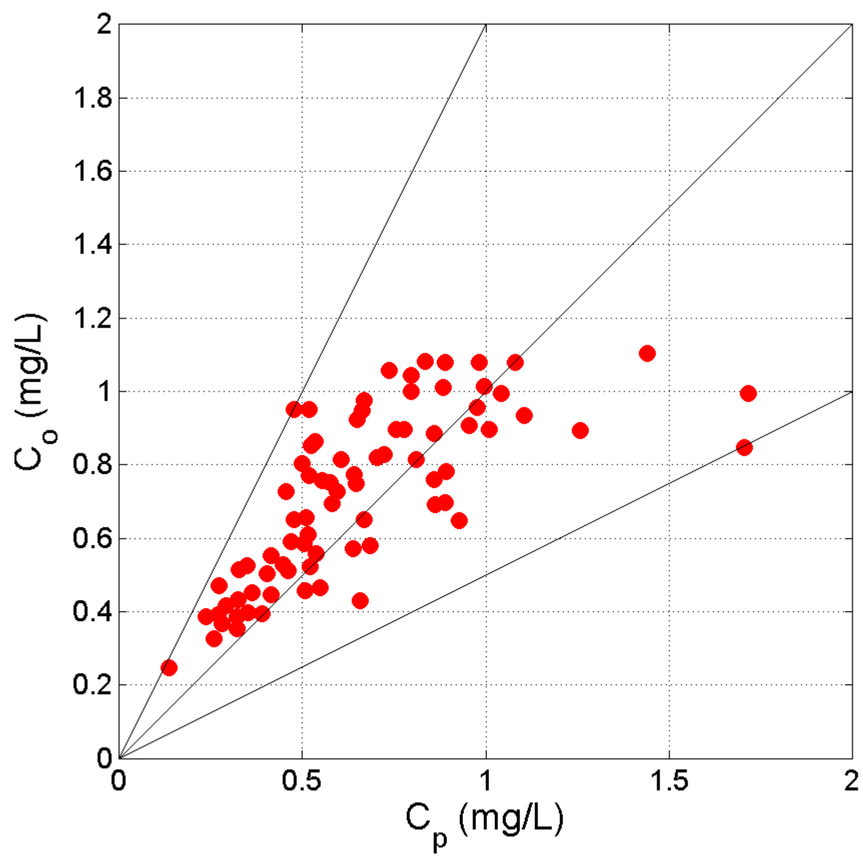
[a]Fractional change in cumulative wet-sulfur deposition for April 12, 1981, as a result of a 50% reduction in SO_2 emissions.

Role of H_2O_2

- Revealed in long-term concentrations



With oxidant limitation



Without oxidant limitation

Role of Non-precipitating Clouds

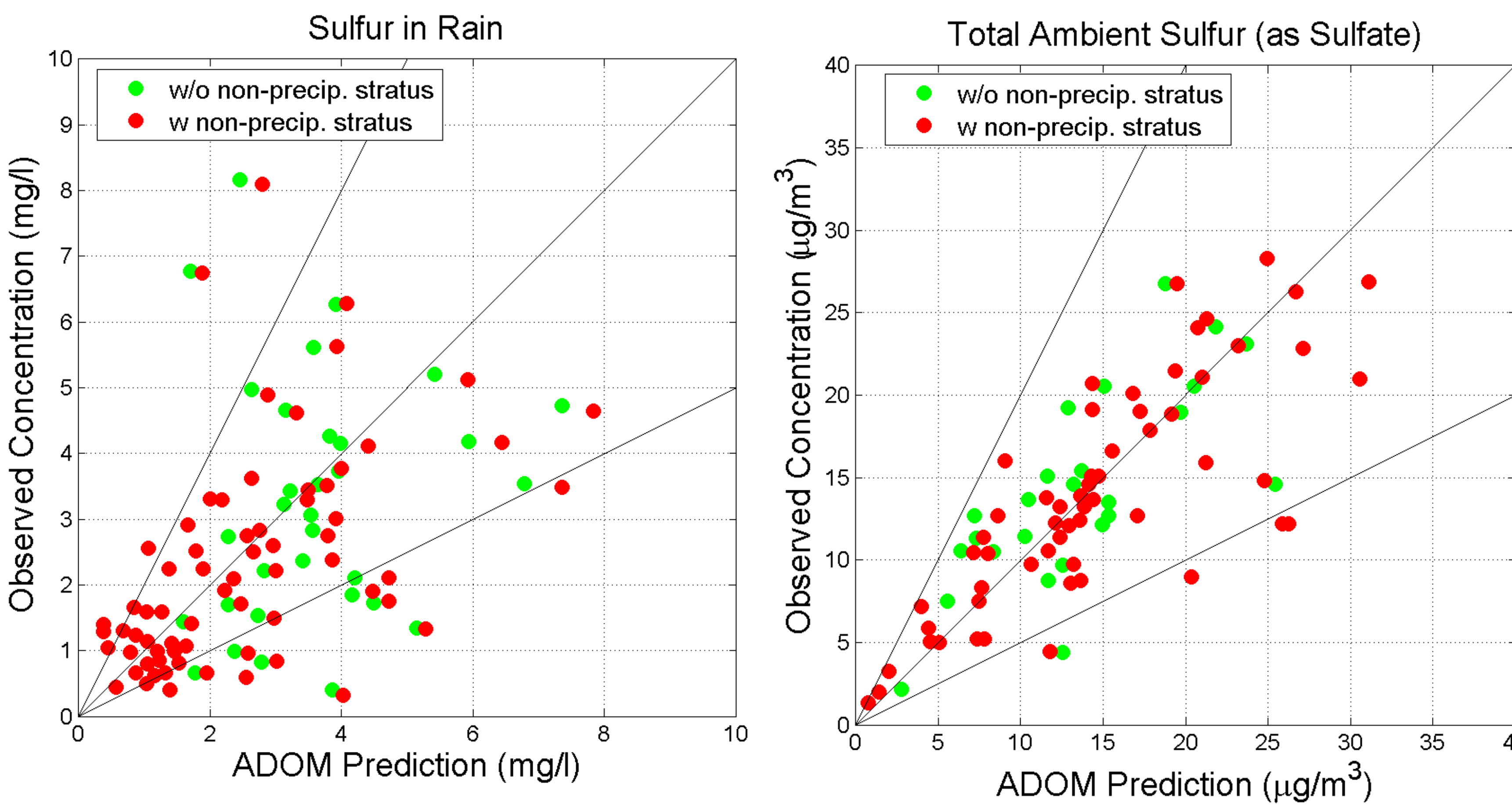
Simulation of a 12 day period in 1998 showed that

- Sulfur in rain was estimated well
- Total ambient sulfur estimated well
- Sulfate in air underpredicted
- SO_2 in air overpredicted

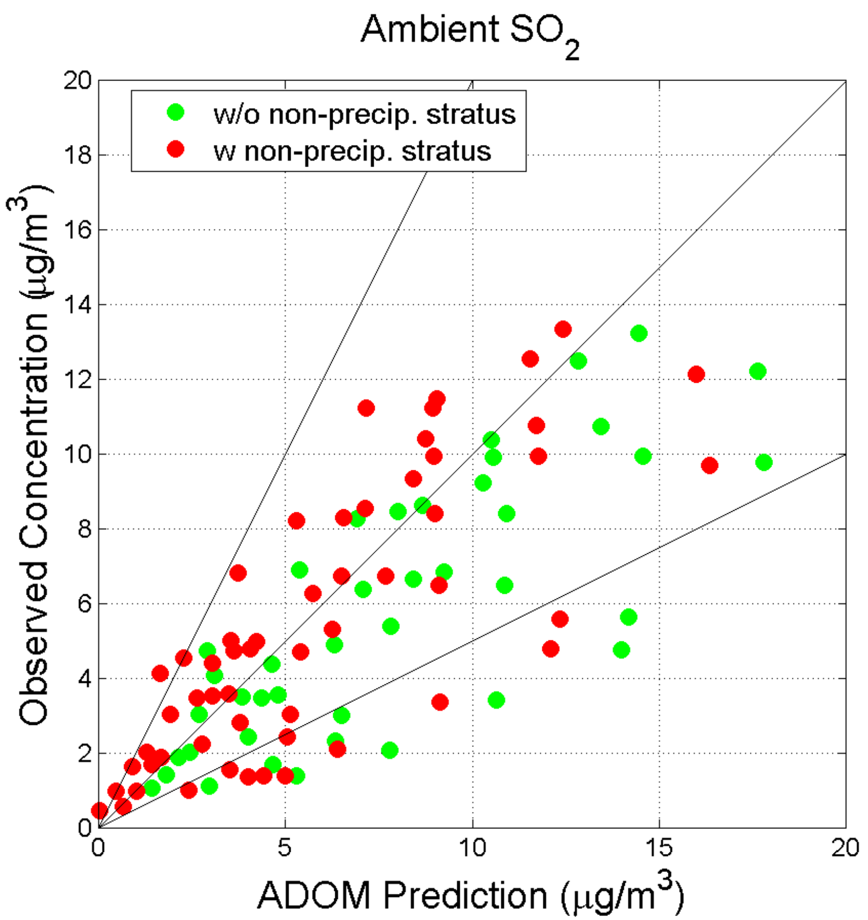
Hypothesis

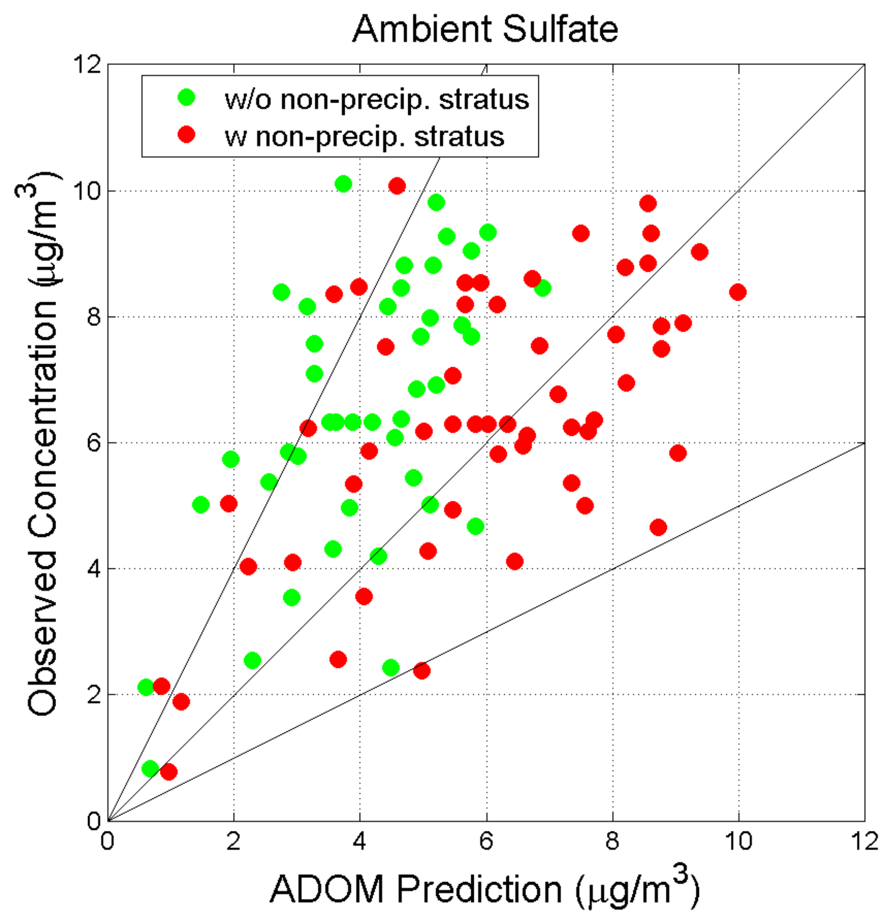
Oxidation in cloud results in ambient sulfate when the cloud evaporates

Role of Non-precipitating Clouds – results from *Karamchandani and Venkatram, 1992*

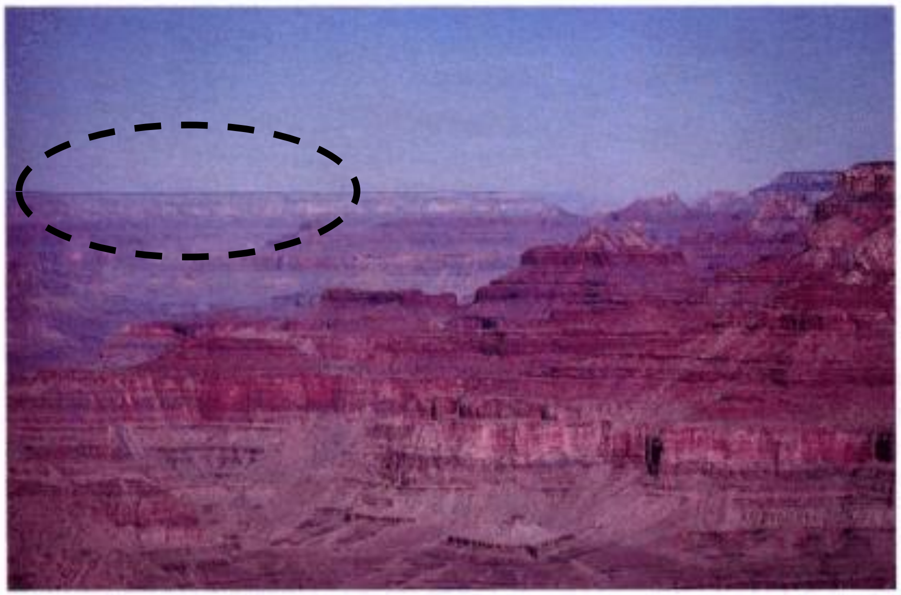


Role of Non-precipitating Clouds - results

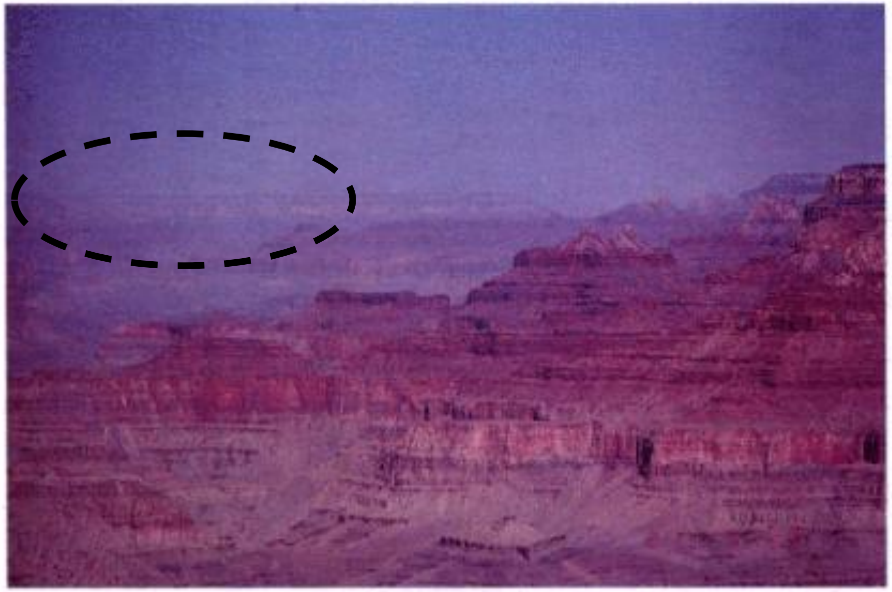




Models are used to estimate the contributions of pollution sources to visibility reduction



Visibility is reduced by scattering of light by aerosols



Results from simulations

- Established culpability of different sources to acid deposition

Receptor Source	US	Canad a
US	70%	70%
Canada	30%	30%

- Showed the importance of sulfate formation in non-precipitating clouds

Urban Air Pollution Modeling

- Non-uniform surface characteristics and buildings
- Complex flow and turbulent fields

Use flat-terrain models with modifications in plume spread

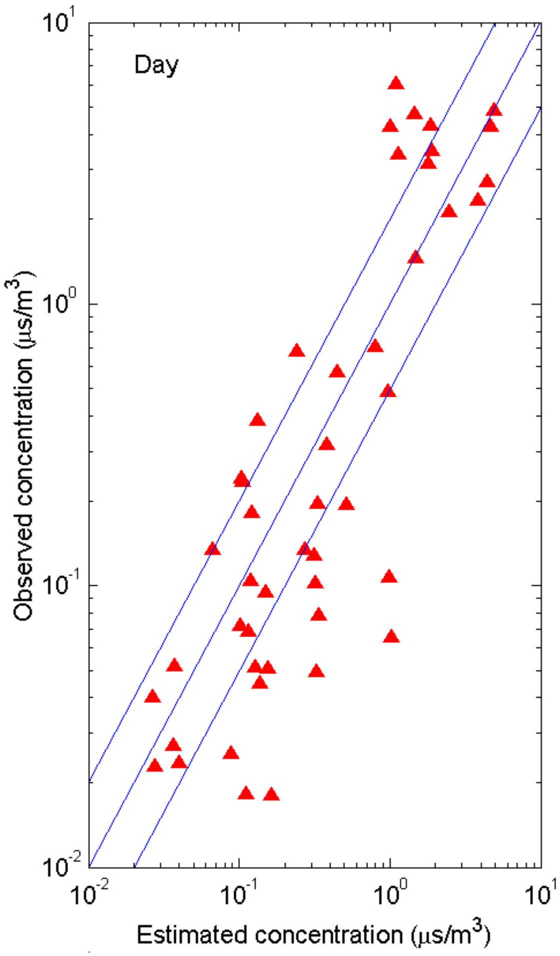
St Louis Experiment

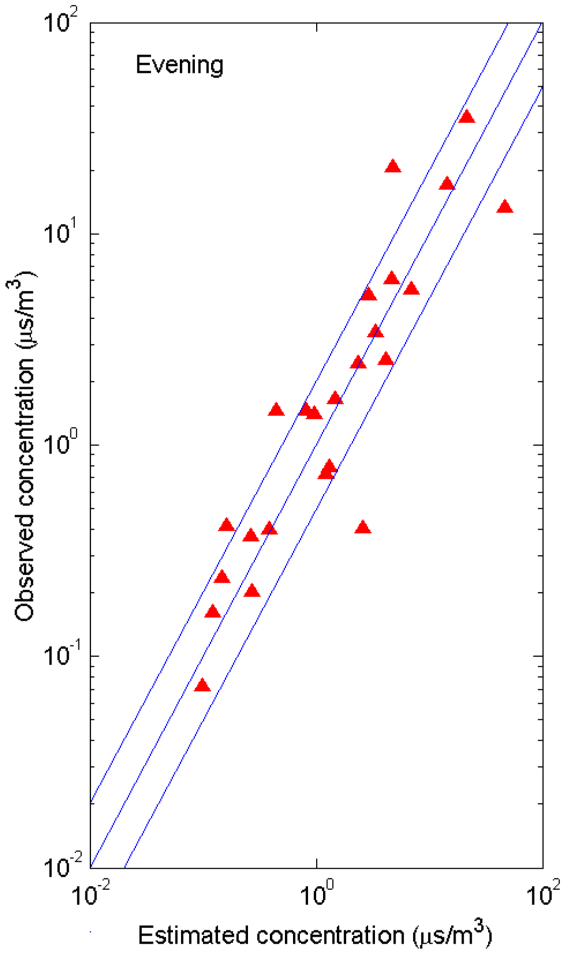
- Conducted in 1963-65
- Zinc Cadmium Sulfide particles released close to the surface
- Doses sampled at 30-50 locations on arcs ranging from 800 m to 16 km from the source along the estimated plume centerline
- Meteorology measured at three surface stations and an instrumented TV tower in the middle of the city
- Resulted in 26 daytime and 16 evening hour-long experiments

Analysis of Data

- McElroy and Pooler derived horizontal spreads from arc doses, and vertical spreads from maximum ground-level concentrations
- They presented these spreads as functions of stability parameters
- Briggs (1973) presented analytical forms that fit the data
- Used in ISC model as urban dispersion curves

St Louis Model Performance
Briggs Curves





Current Urban Pollution Problems

Environmental Justice

Freeways through neighborhoods

Need models for ~1 m scale dispersion !

Sources Near Residents

Urban Field Experiments

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

- 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 study- September 2003, 2004

Funded by CEC and ARB to examine Environmental Justice Issues

Dugway Experiment

CE-CERT Parking Lot

Meteorological Measurements

Sampling Sites

- 74 sites

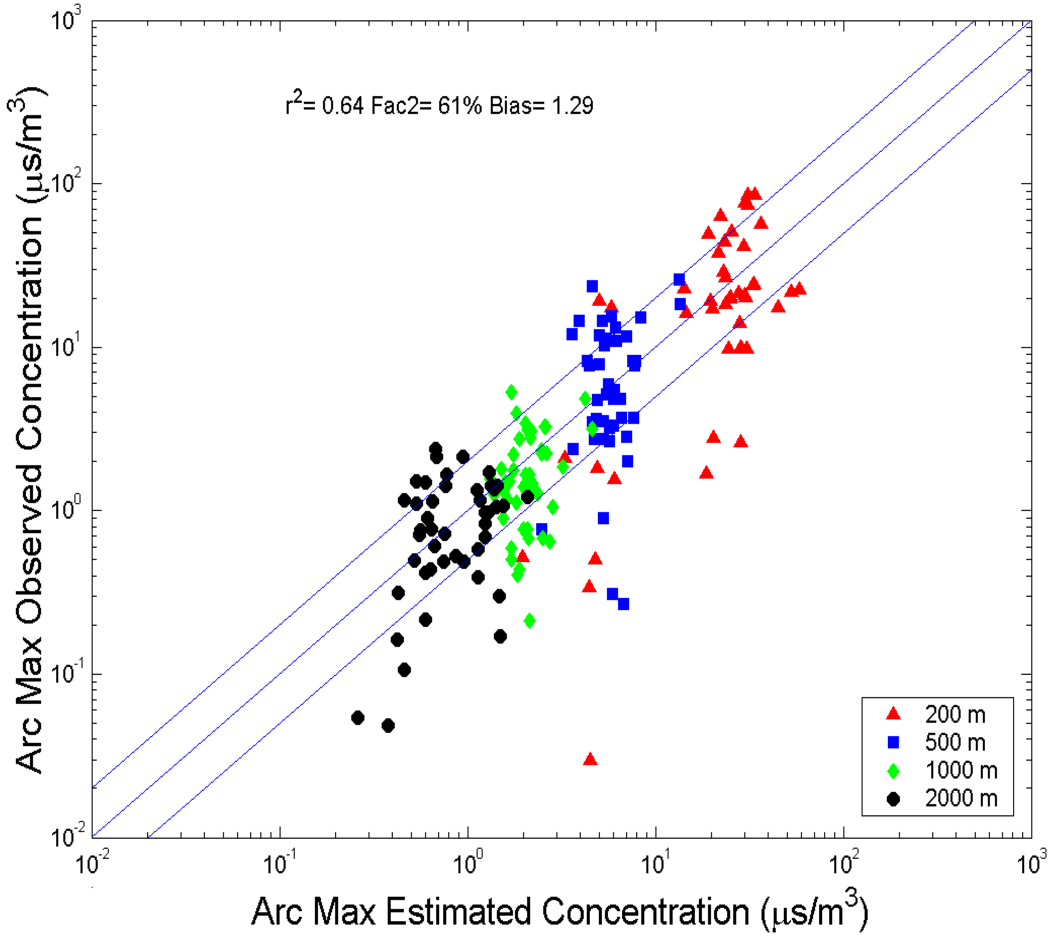
Wilmington/Long Beach Field Study

Locations of sodar and sonic tower

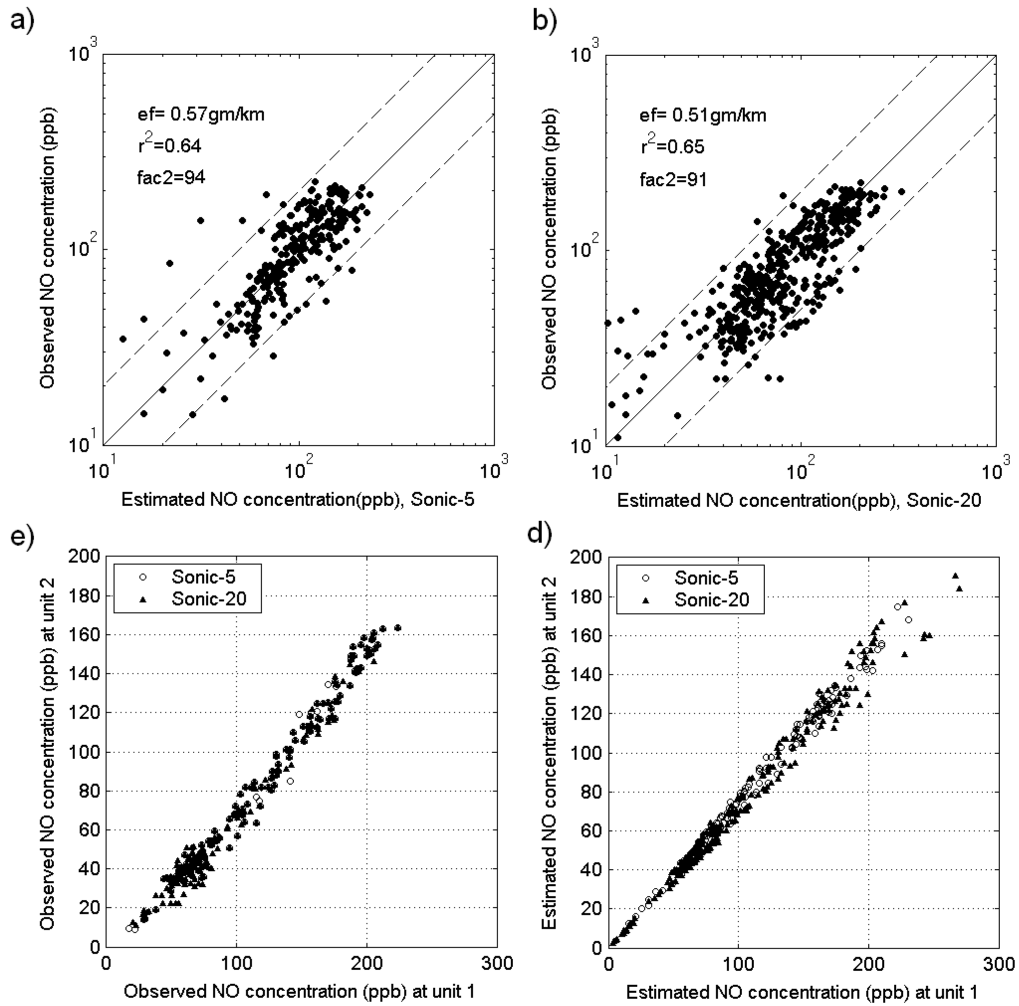
Wilmington Park Elementary School

LADWP tracer release sonic mini-sodar

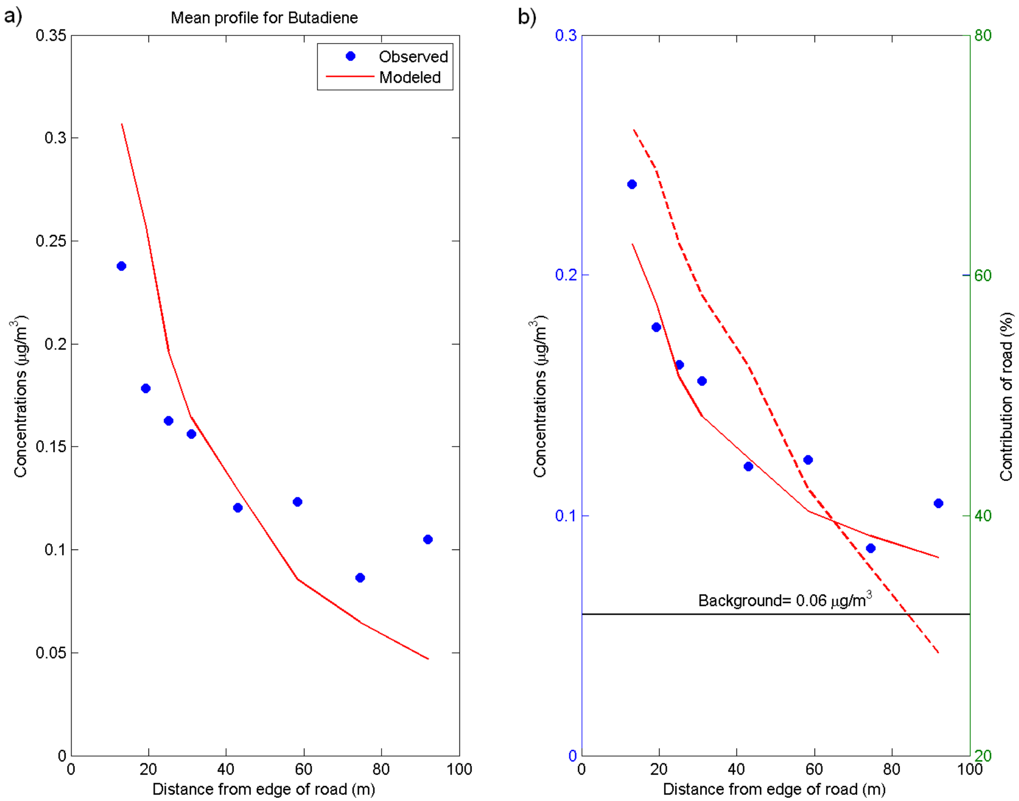
Model Results using Boundary Layer Information and Initial Spread



Model Results –Highway Modeling



Freeway concentration contributions



1-3 Butadiene Concentrations

Simple models work well

BUT…

- Simple models for dispersion provide adequate concentration estimates if mean wind and turbulence velocities are known

$$\textit{Point sources:}$$

$$C \sim \frac{Q}{u_{dil} x^2}$$

$$u_{dil} = \frac{\sigma_w \sigma_v}{U}$$

Estimating model inputs from urban routine measurements

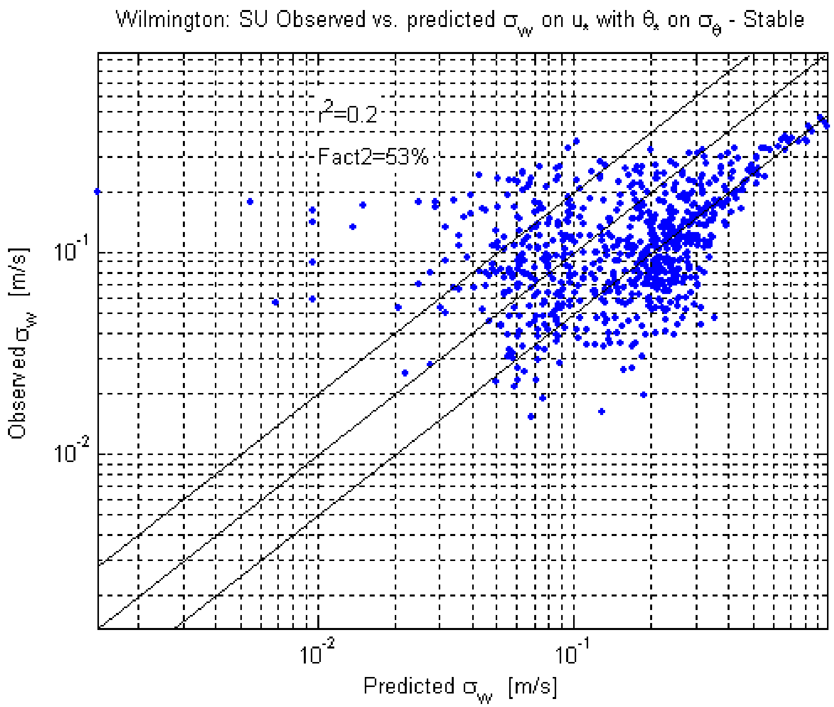
One or two level measurements of winds and σ_T can be used to estimate urban parameters.

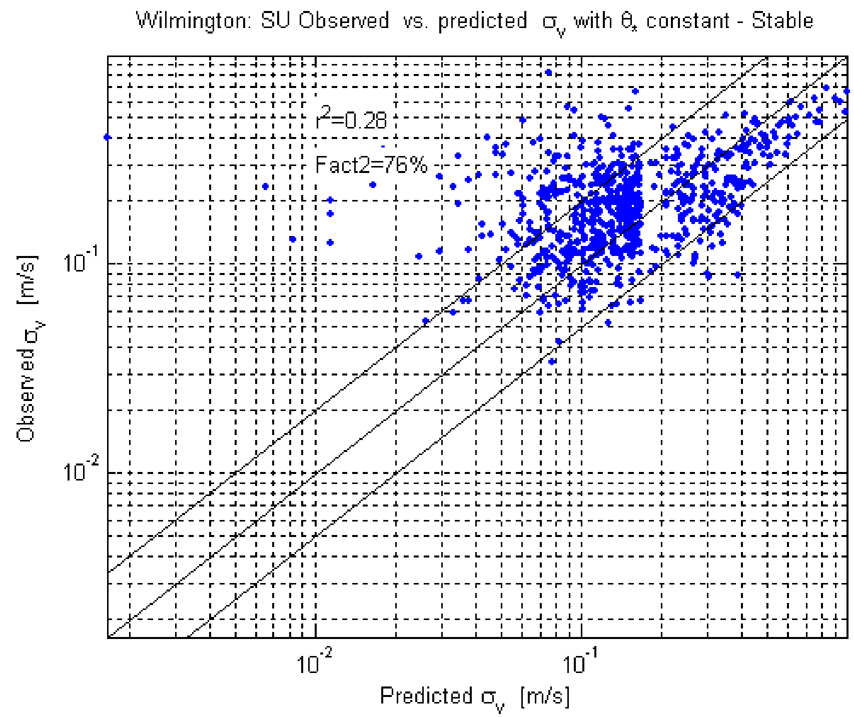
Results-Stable Conditions

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

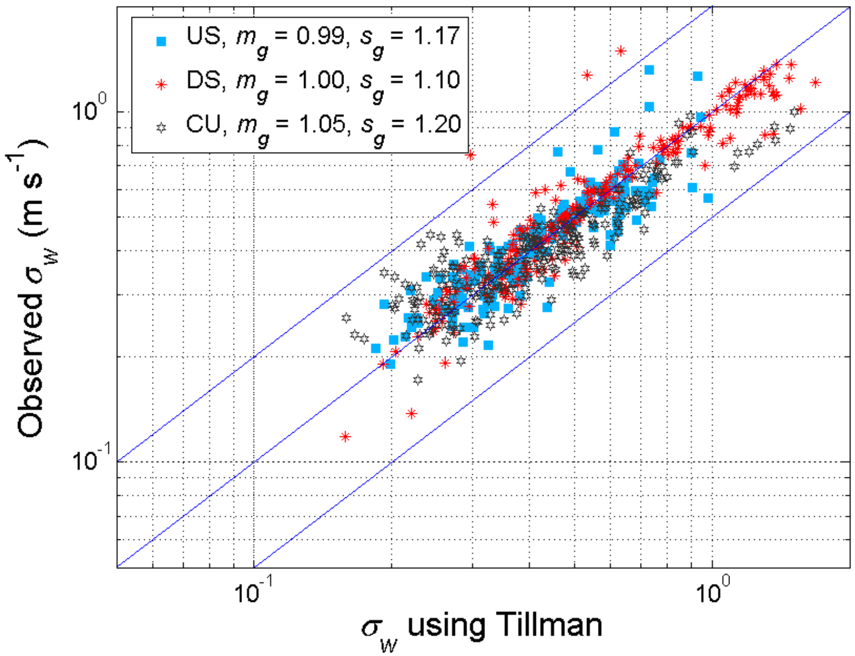
$$\sigma_w = 1.6u_*$$

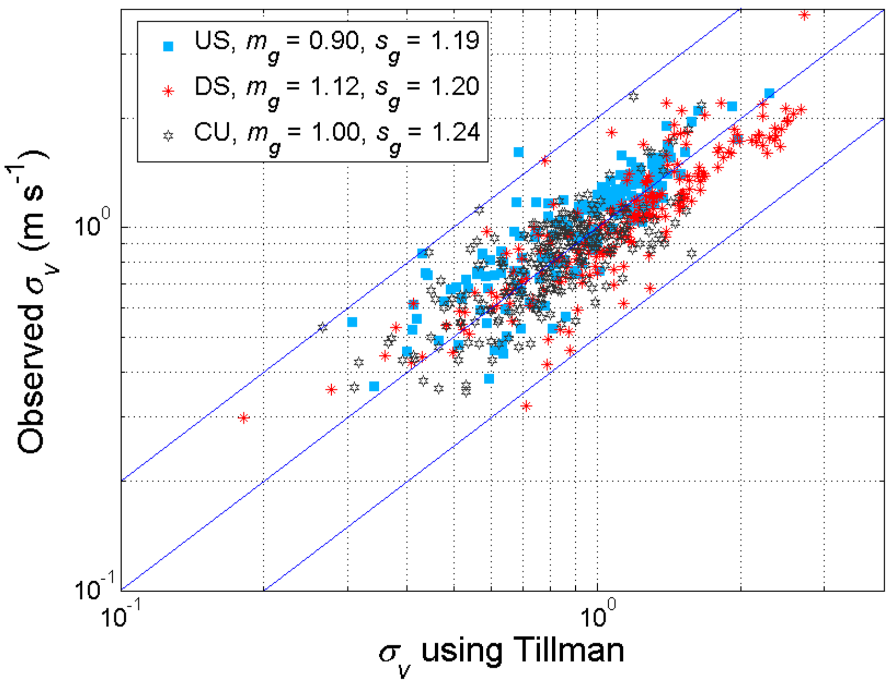
$$\sigma_v = 1.9u_*$$





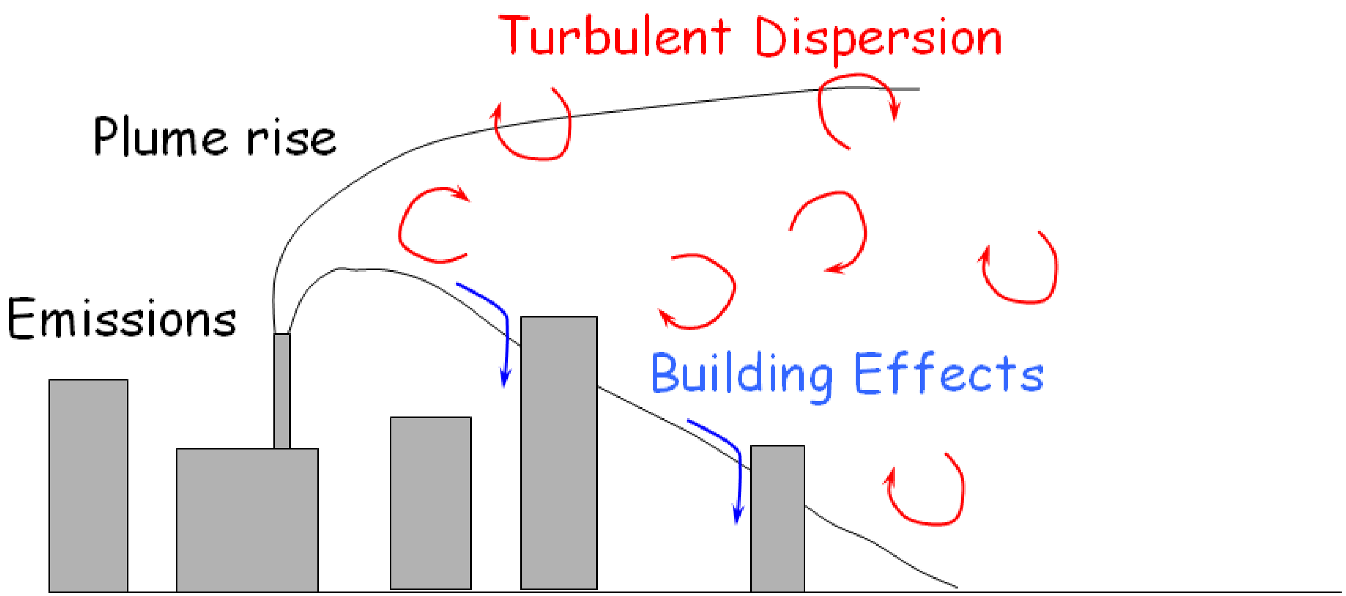
Results-Unstable Conditions



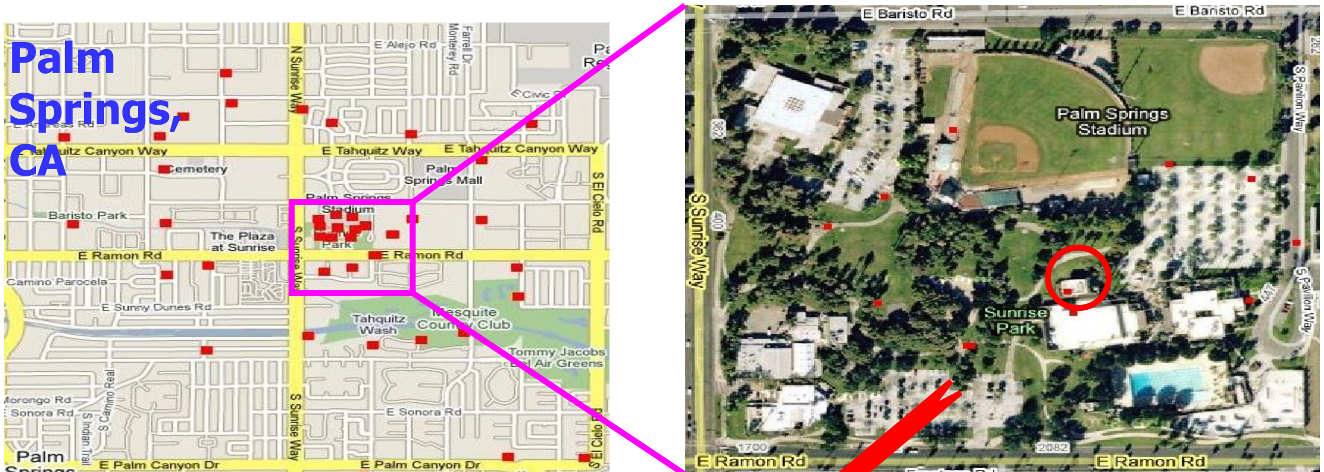


Dispersion Models

- Simpler models are not appropriate for estimating concentrations within a kilometer from source when plume is still in the urban canopy
- Need numerical and/or physical models

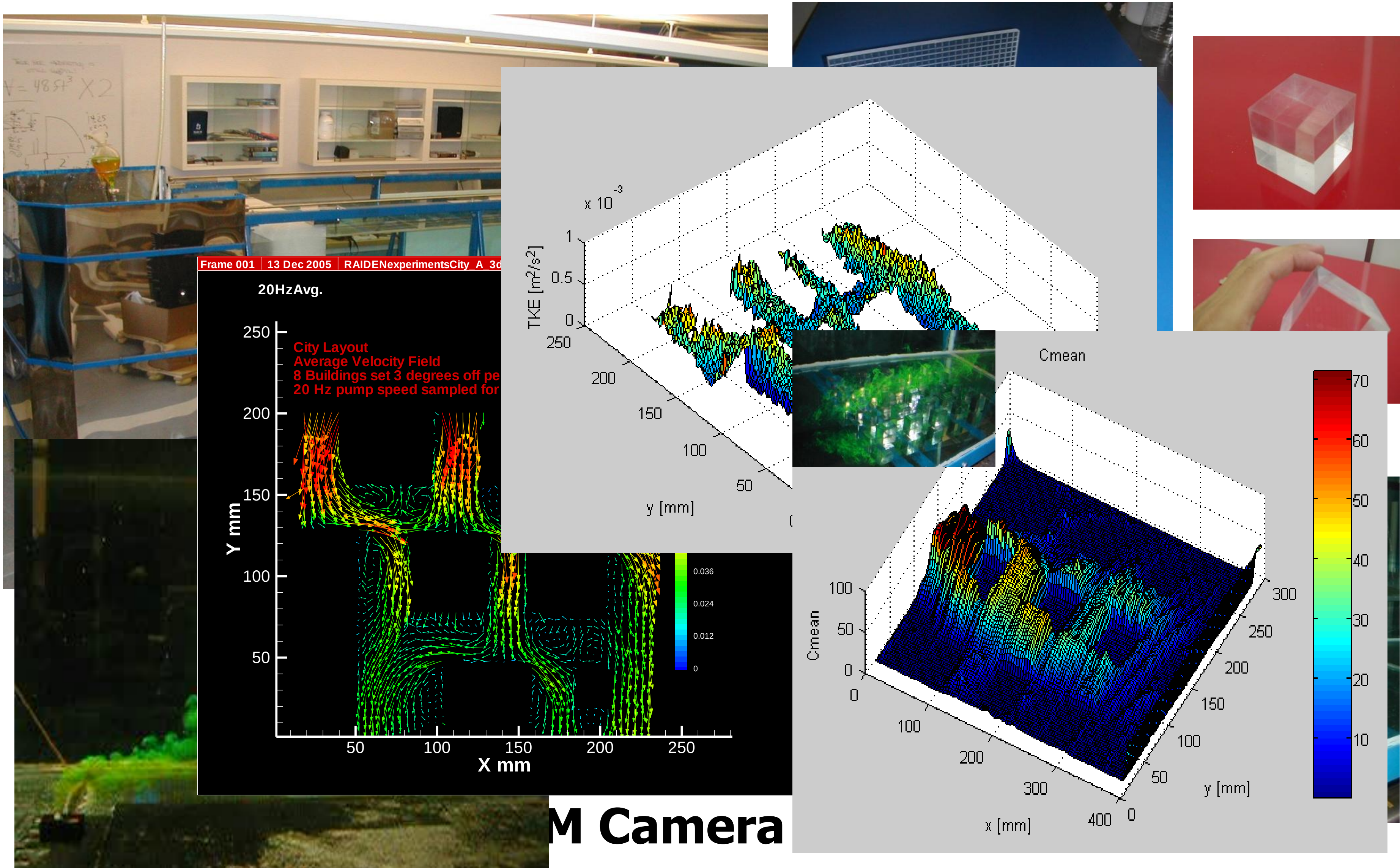


Impact of distributed generators

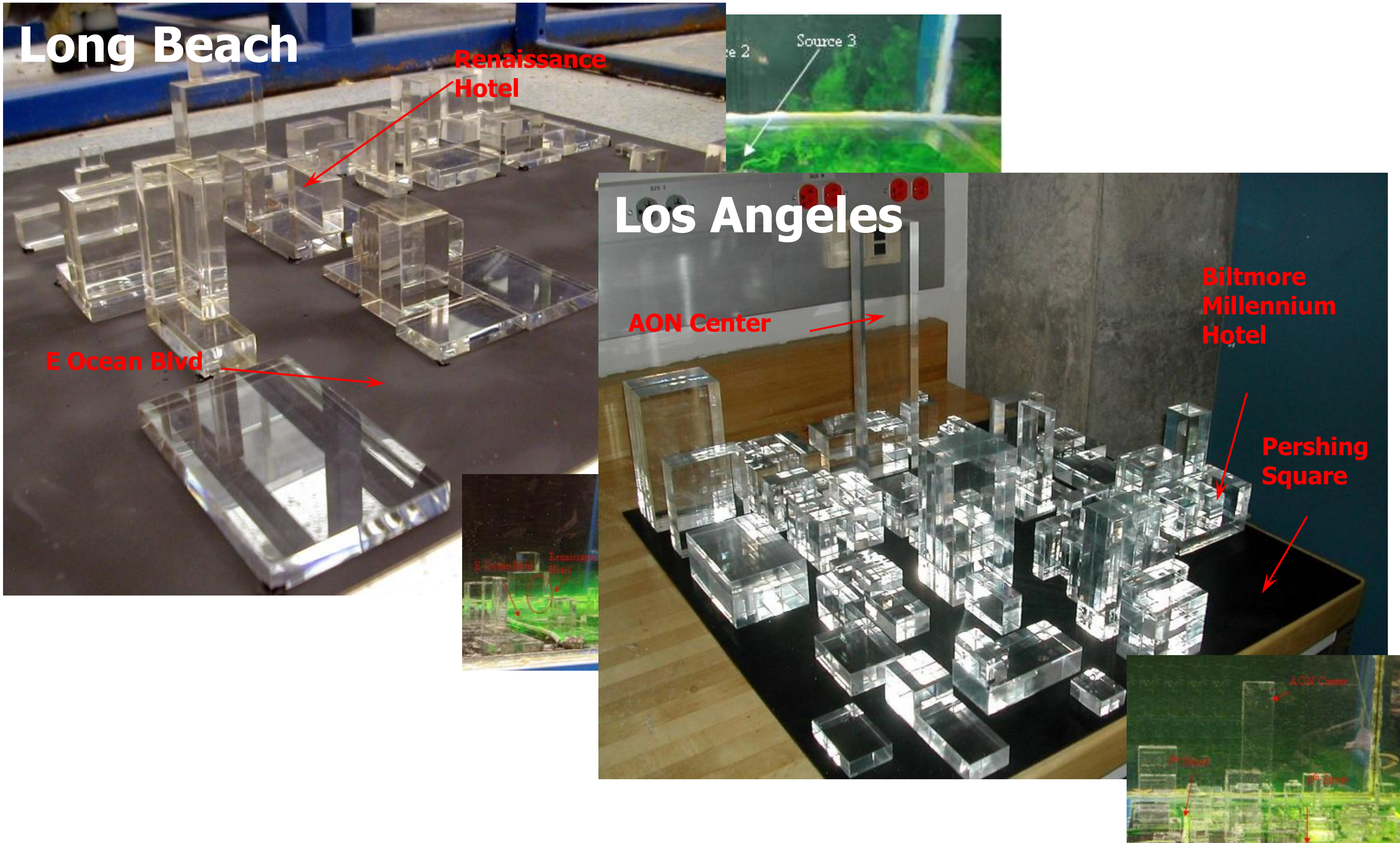


Palm Springs site

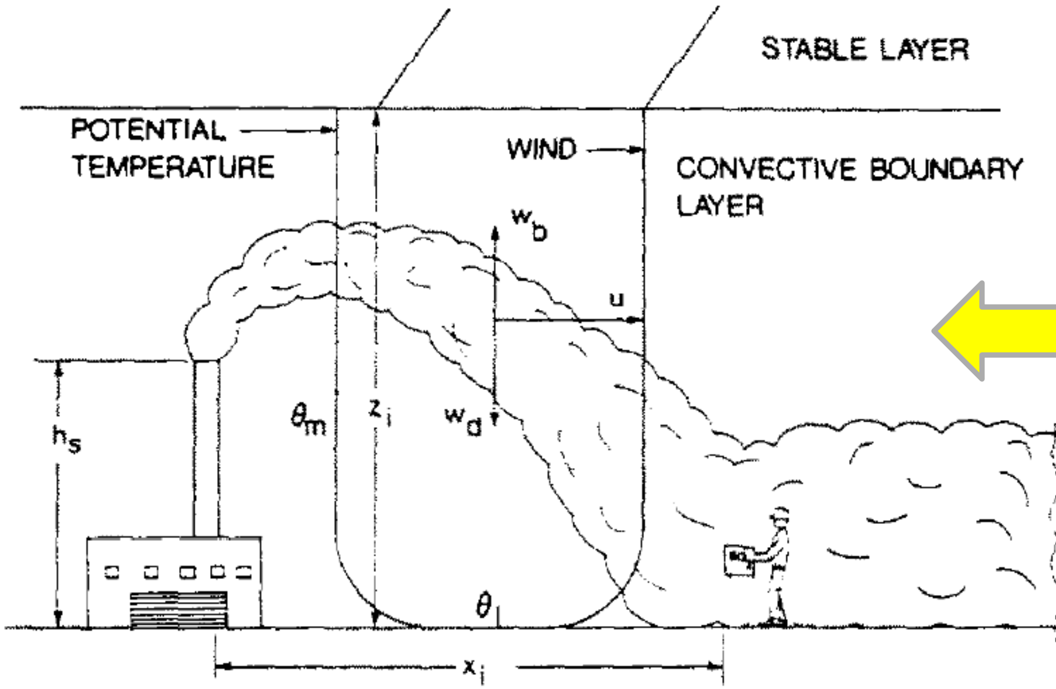
Laboratory modeling

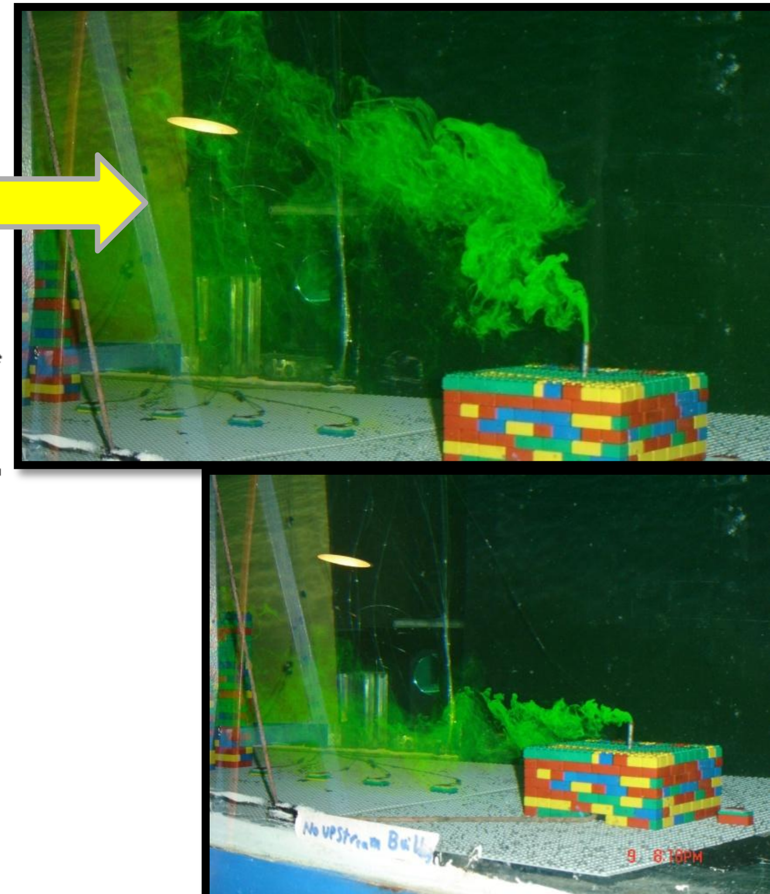


From Simple to Complex



Is Urban Canopy Layer "Convective"?





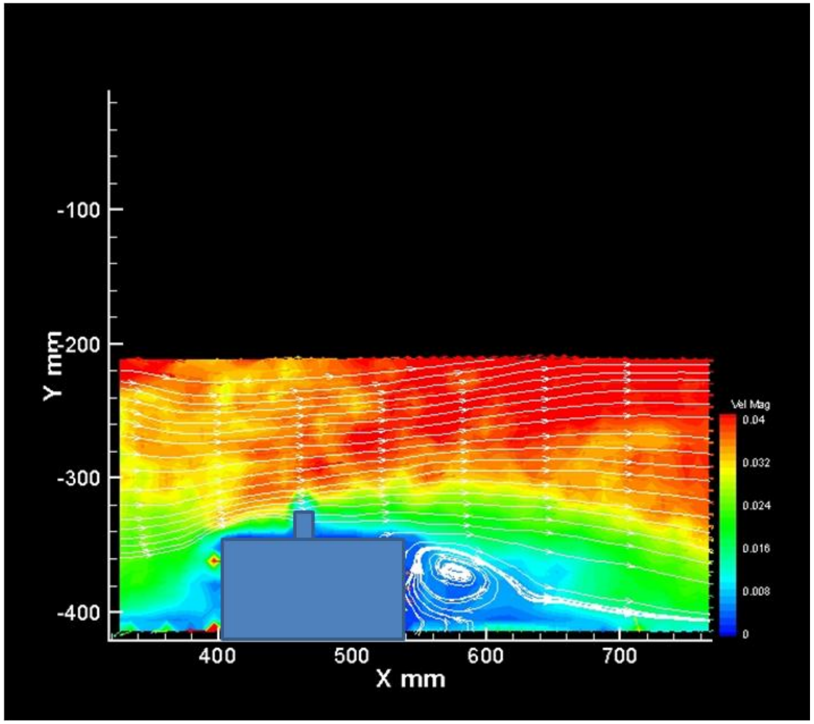
$$C(x,0,0)=\frac{Q.f(x)}{\sqrt{2\pi}\sigma_y\sigma_z.U}$$

$$f(x)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{p}\exp\left(-\frac{t^2}{2}\right)dt$$

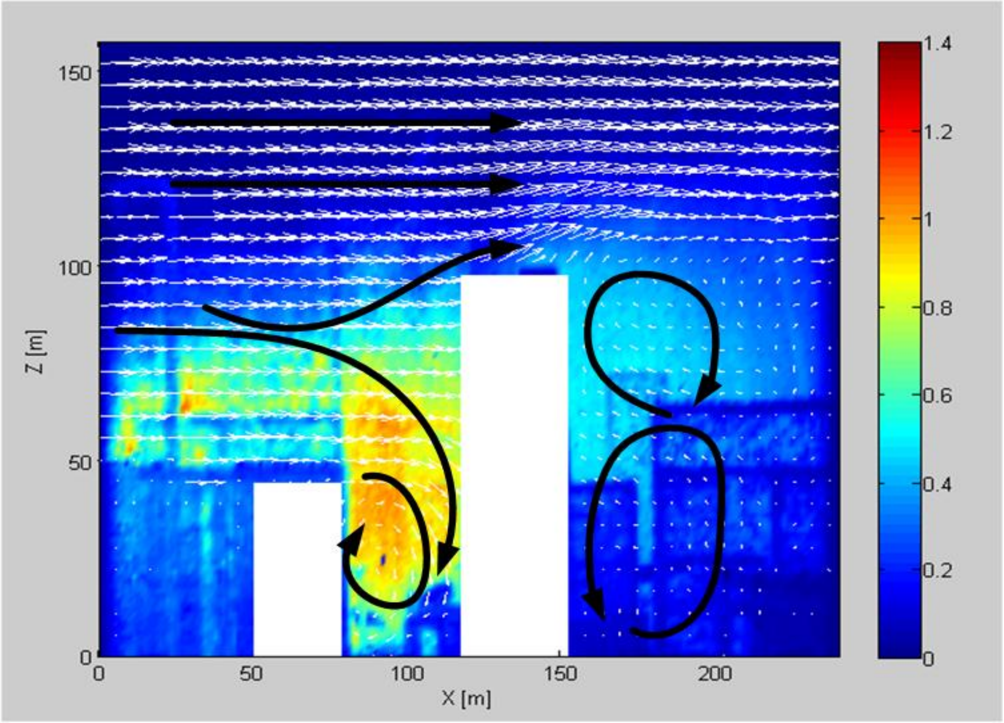
$$p=\frac{\ln\left(\frac{x}{x_i}\right)}{\ln\left(s_g\right)}\ where\quad x_i:\ F^{1/3}x_i^{2/3}-w_d x_i+h_s U=0$$

$$\sigma_y=\frac{\sigma_v x}{U},\sigma_z=\frac{\sigma_w x}{U}\qquad w_d=0.5w_*$$

Impact of individual buildings

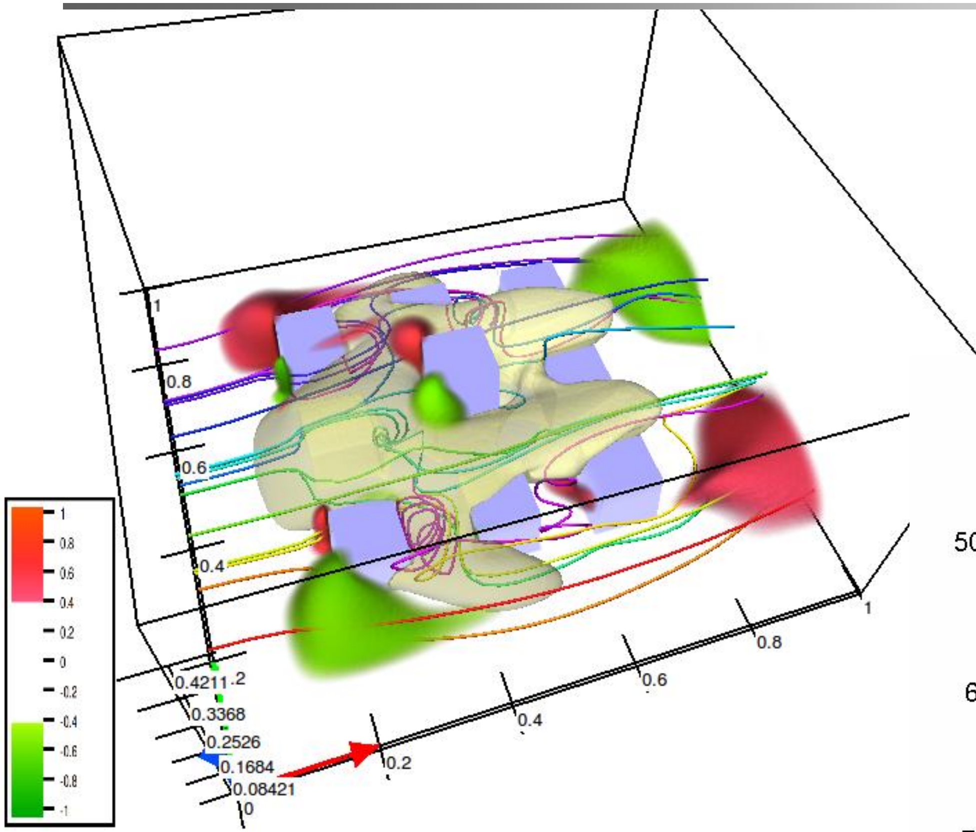


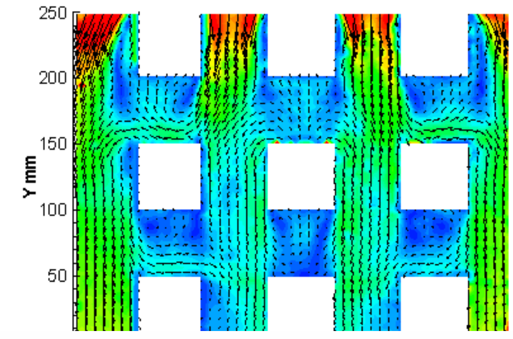
Flow behind a distributed generator

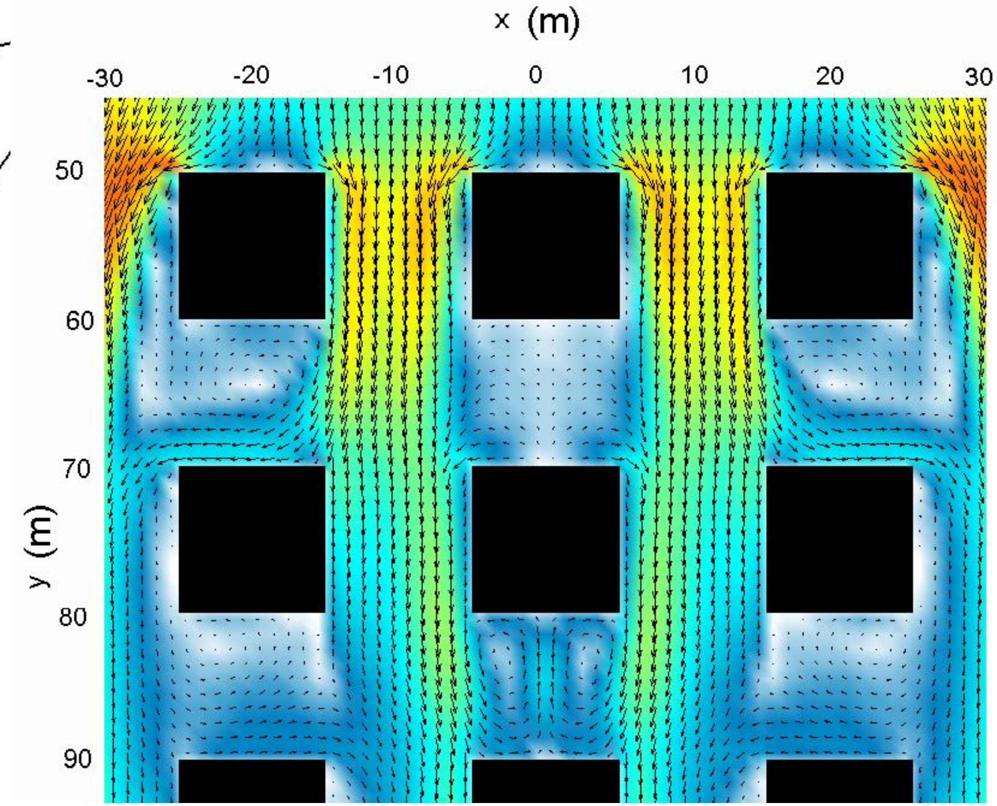


Chimney effect of a tall building

Performance of Numerical Models







J.J. Baik, S.B. Park SNU

Summary

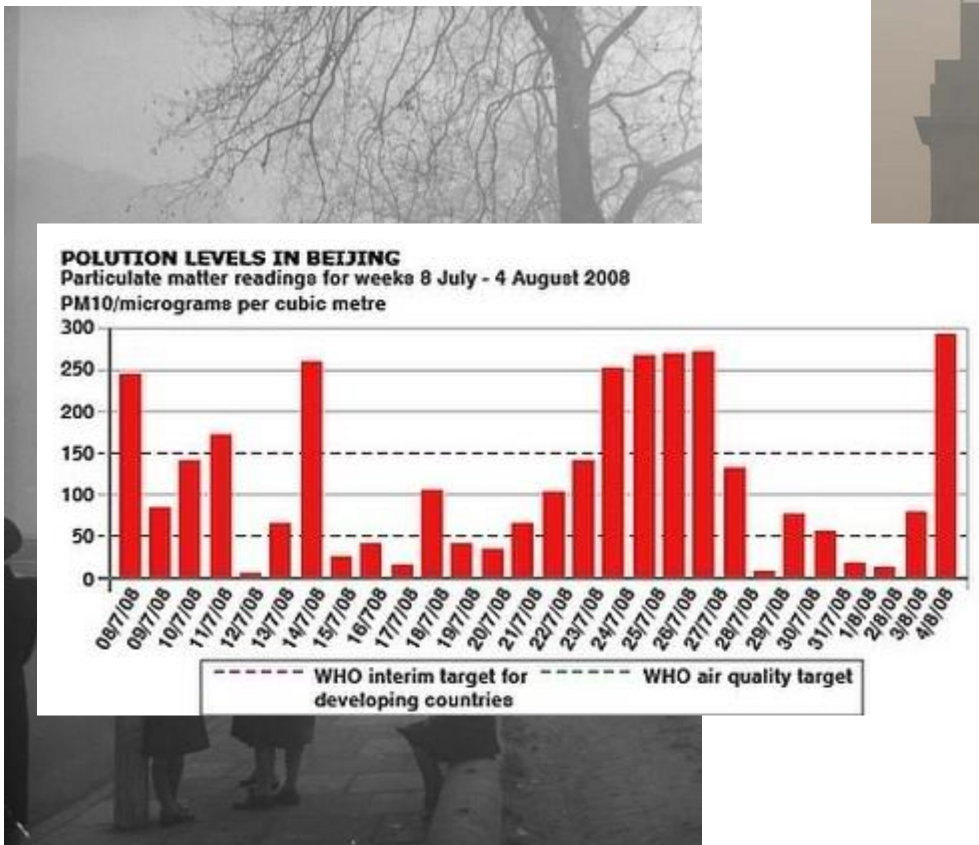
Understanding of air pollution problems is gained through

- Basic science
- Field studies and laboratory experiments
- Modeling/Simulation

How is this going to change in the future?

Past and Future

Delhi, now



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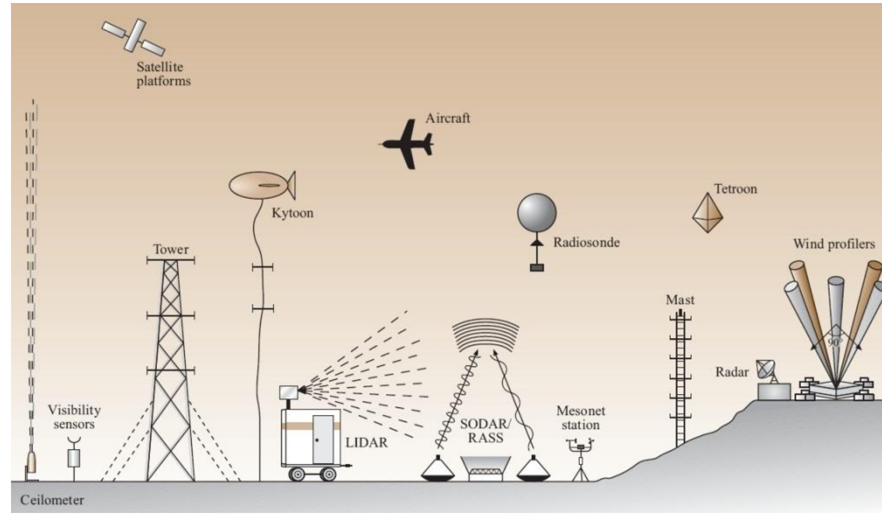
Beijing, now

London, 1952

Per capita

The Future

- Measurement techniques will become more sophisticated and perhaps less/more expensive



- Models will become more comprehensive and output will be more realistic with increase in computational power

On Using Comprehensive Models

- Inevitable errors in numerous model inputs make model evaluation a difficult exercise
- Numerical errors
- Finite grid sizes create false effects-mixing and chemistry
- Responses of the complex model are very difficult to interpret
  - Need to draw generalizations based on model results that are “messy” as reality

Future of Modeling

- Need both comprehensive as well as simpler semi-empirical models
- Simple models provide insight that is more difficult to obtain from complex models
- Might need simple models to interpret results from complex models

Acknowledgements

- Collaborators over the past 30 (?) years
  - Prakash Karamchandani, Marko Princevac, David Pankratz, Dennis Fitz
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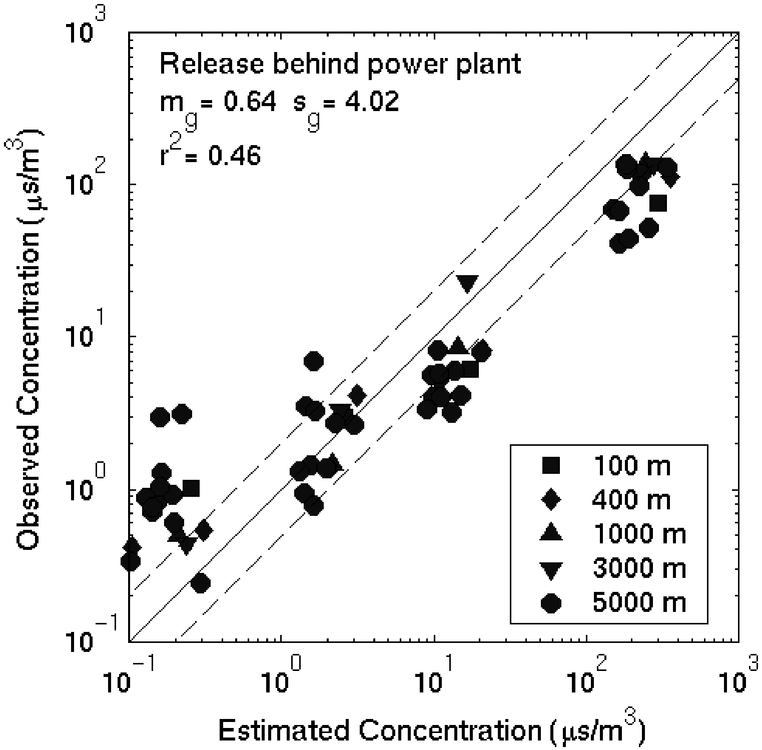
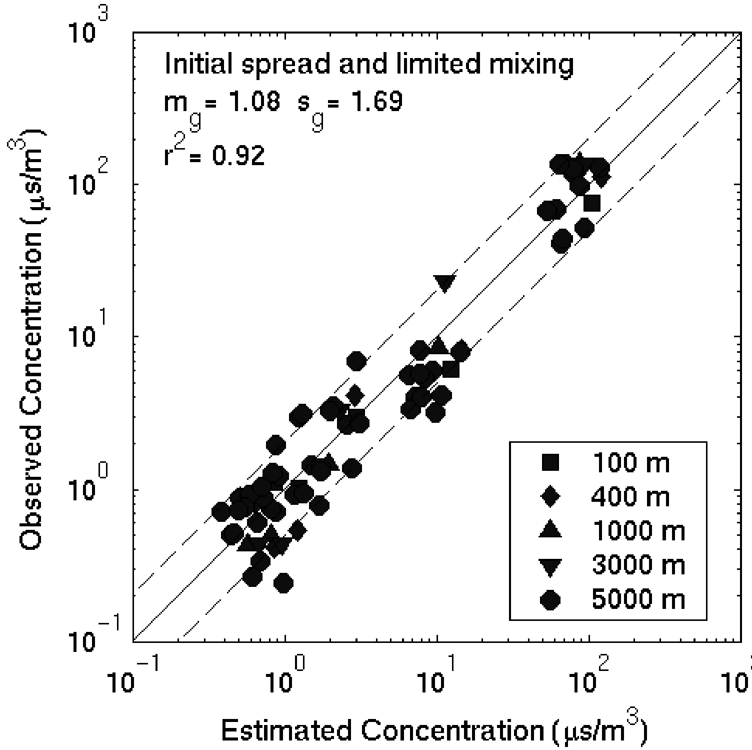
- EPRI, USEPA, CEC, CARB, NSF, Ontario Environment, Umweltbundesamt

Model Performance





Field study next to major highway in Raleigh, North Carolina,