The influence of Ambient Meterology on Nanoparticle Concentration in an Urban Setting

Mr Prashant Kumar

Dr Paul Fennell (presenting)

Prof. Rex Britter

Background

- Vehicles are the major source of ultrafine (<< PM 2.5) particles in the ambient atmosphere in cities.
- Stringent controls over the total **mass** of particles emitted by diesel cars may simply have shifted the problem to produce more ultrafine particles.
- Urban street “Canyons” prevent efficient dilution and removal of particles by clean air from above.
- Most measurements are time-averaged over a minimum period of minutes. Acute effects may be better correlated with maximum, rather than time-averaged exposure.
- We have observed PNCs (particle number count) in excess of **1000** times higher, from ambient sampling, over short periods of time than the long-term average PNC.[1]

[1]P. Kumar; P. Fennell; D. Langley; R. Britter, *Atmospheric Environment (In press)* **2008**.

Ultrafine Particles

- May be more toxic than larger particles per unit mass.
- Contribute little to total mass, and so are currently subject to little regulation.
- Contribute most to the PNC (particle number count).
- Are more difficult to measure than larger particles.

Our Research Methodology

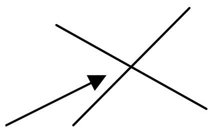
To make measurements using a time resolved particle spectrometer (DMS 500), in conjunction with time-resolved measurements of ambient windspeed and direction (and other meteorological conditions).

These measurements should allow better understanding of dispersion, deposition and ventilation of nano-particles from the urban environment.

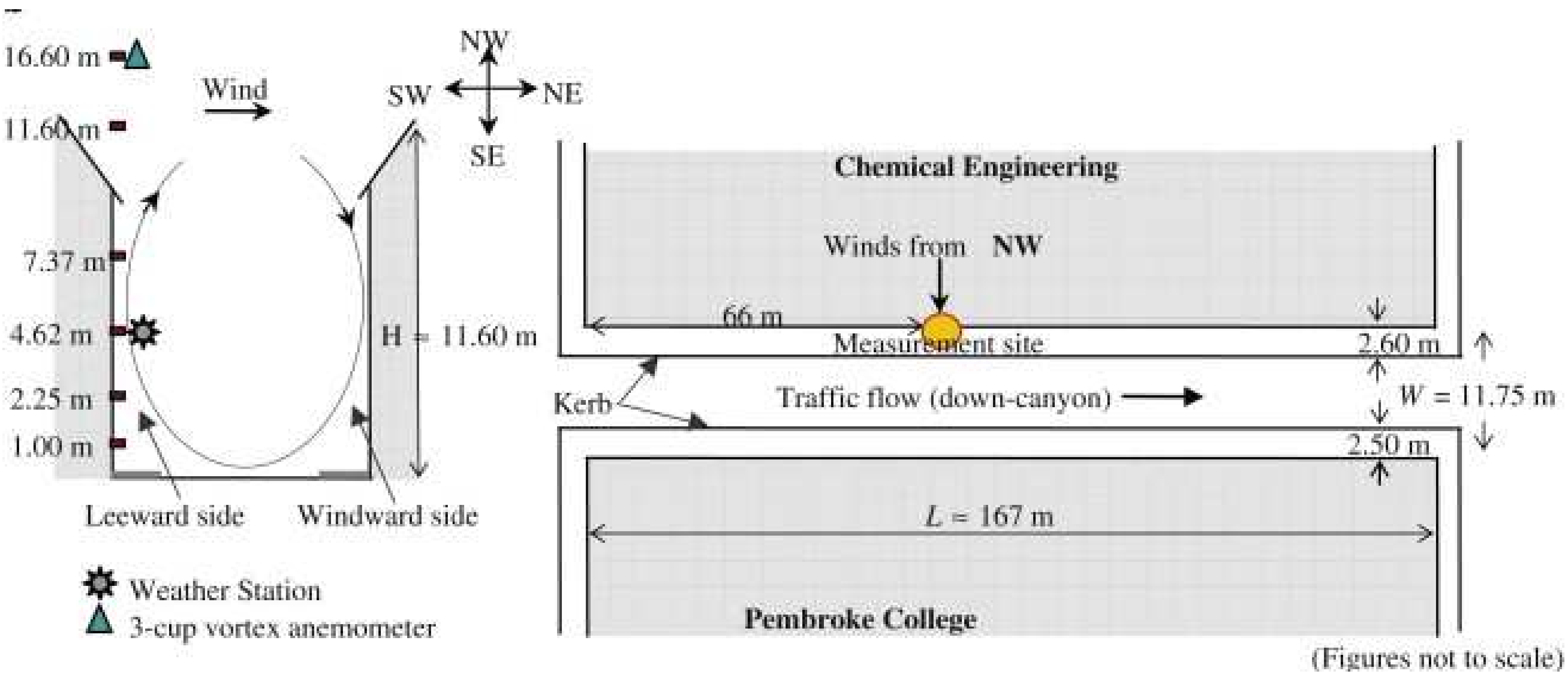
Location of Experiments

- Engineering Department, Cambridge (preliminary experiments).
- Chemical Engineering Department, Cambridge (protracted sampling campaign).
- Possibly better represent the results in small towns and less busy cities than measurements made in larger metropolitan areas.
- That’s our story, and we’re sticking to it.


Wind direction from NW
Sampling Site
Trinity College
Gonville and Caius College
Trinity Hall
OLD SCHOOLS SITE
Clare College
King's College
MUSEUMS SITE
Queens' College
SILVER STREET/ MILL LANE
Pembroke College
DOWNING SITE
Emmanuel College
Christ's College
Christ's Pieces
BUS STATION
PARKER ST
PARKSIDE
ST ANDREWS STREET
Parker's Piece
0
200 metres
0
200 yards

You are here 

Detailed Description of Site



Rooftop and roadside measurement of windspeed.

Roadside measurement of ambient temperature and humidity.

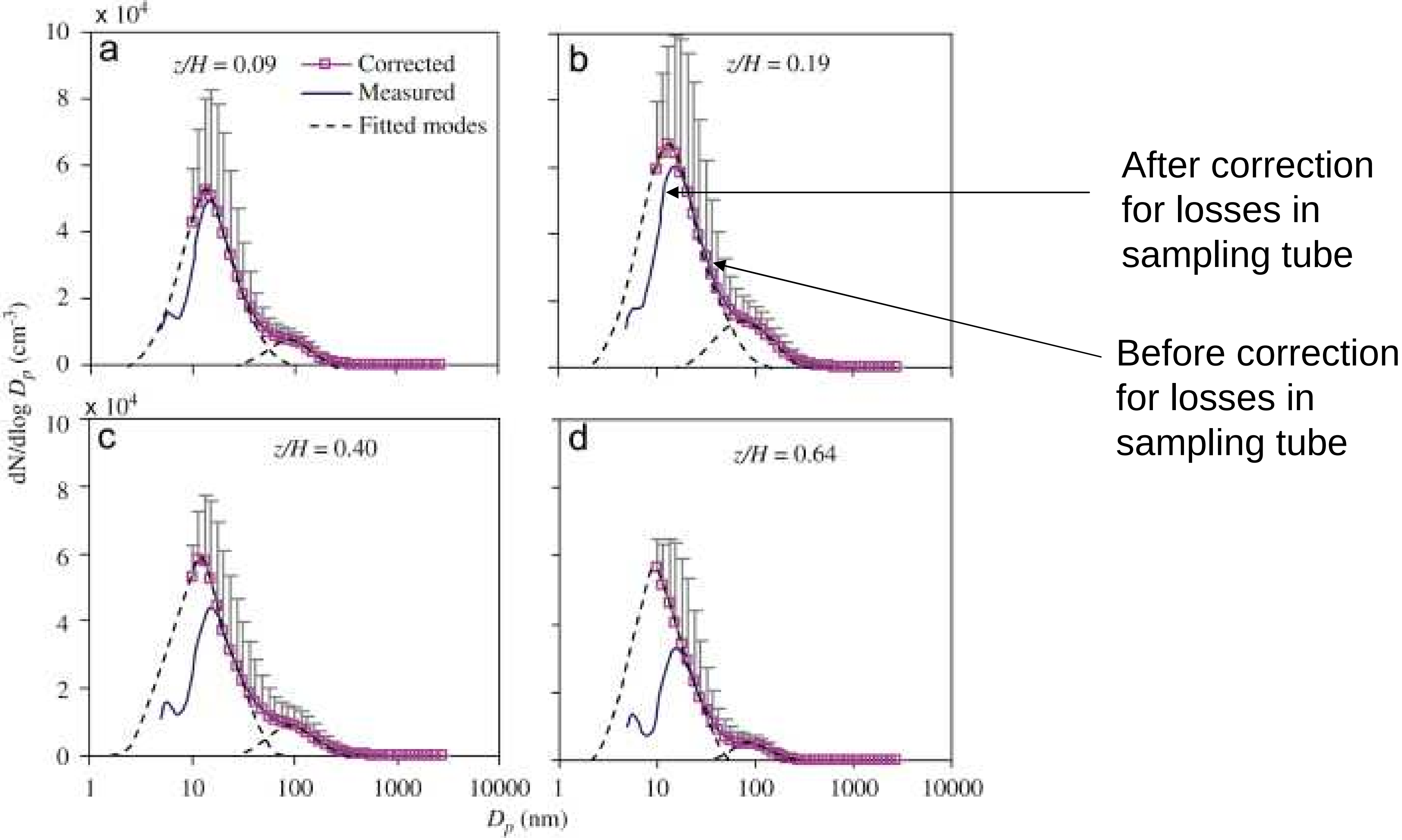
CCTV camera sampled traffic volume, backed up with manual counts.

Question 1.

- What is the variation of the particle number count with height in an urban canyon.
- Alternatively – What height should we sample at to get a measurement which is representative of the exposure of the general population?

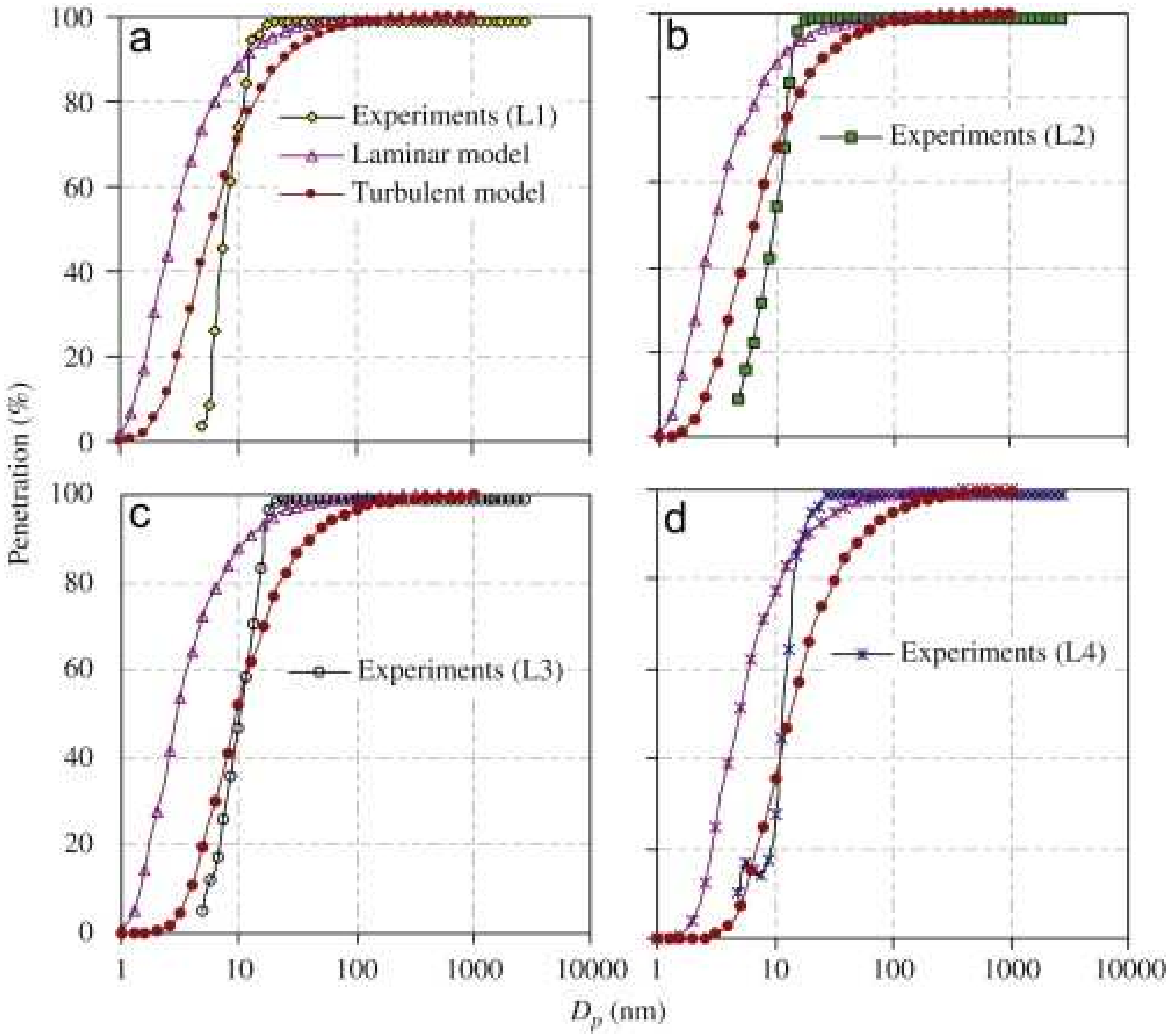
Pseudo-simultaneous Vertical Variation

- **One** instrument, sampling from a variety of different heights
- Novel sampling apparatus used with DMS (switiching system)
- 24 hours total sampling
  - 7.5 m high pole erected outside department
  - Constantly attended (Safety)
  - 4 sampling probes, one DMS, novel switching system
  - Sampled for 60 s at each height, first 15 s discarded (clear lines, equalise pressures and sample flows, etc).
  - Local windspeed recorded every minute by a vortex anemometer situated on a pole on the top of the department.
  - Wind direction half-hourly from AT+T weather station (Engineering). Correlation of average windspeed between the two almost perfect.



x 10^4
a
z/H = 0.09
Corrected
Measured
Fitted modes
b
z/H = 0.19
c
z/H = 0.40
d
z/H = 0.64
dN/dlog D_p (cm^-3)
D_p (nm)
1
10
100
1000
10000
0
2
4
6
8
10
After correction for losses in sampling tube
Before correction for losses in sampling tube

Correction for losses in sampling tubes

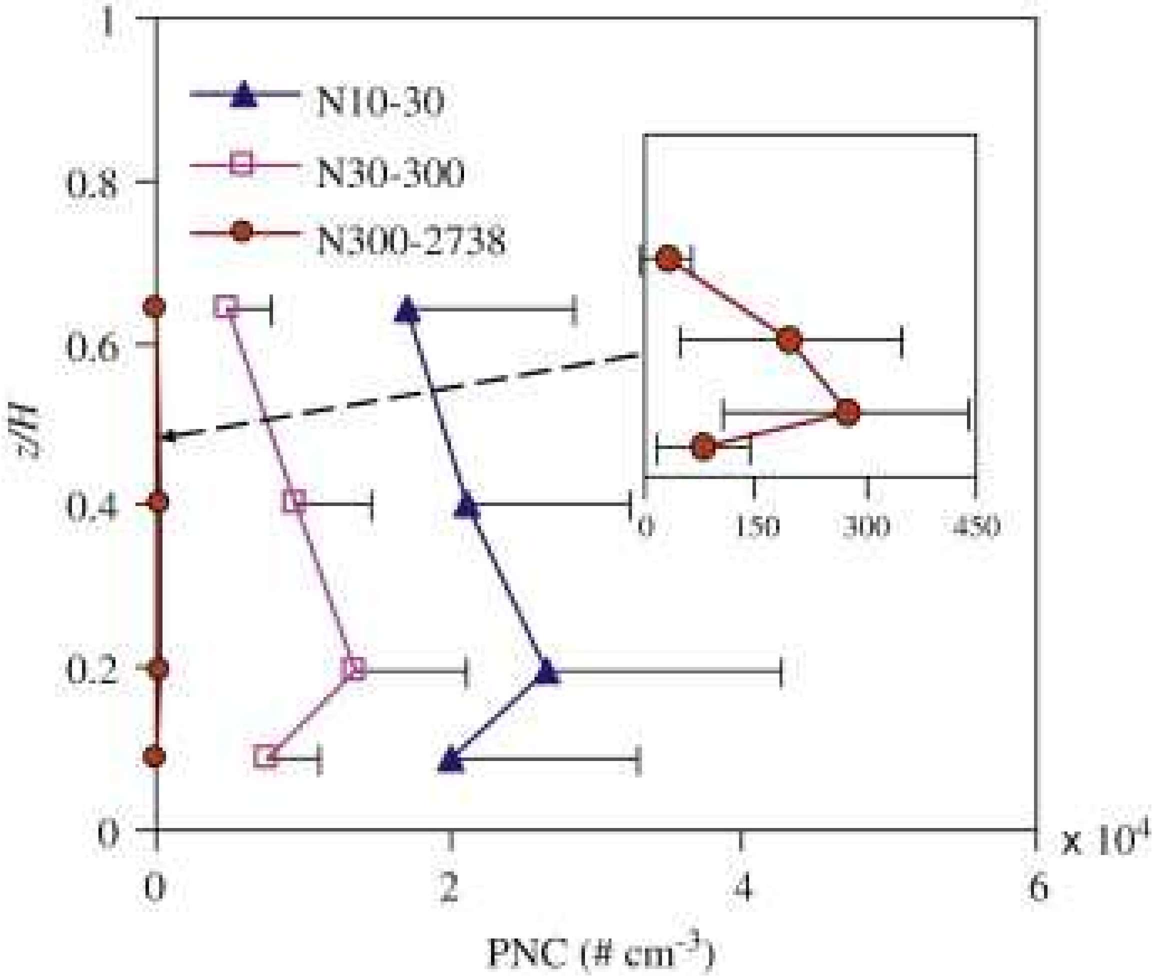


Correction for losses in tubes by sampling from a diesel-engined car and a number of other aerosols.

Though the flow is laminar through the tube, the losses in the tube are higher than would be predicted by models available (Hinds) in the literature.

Confirmed / confirms independent experiments (Cambustion) using both DMS and CPC-SMPS.

Vertical Variation



Maximal concentration of particles at around 2.25 m (z/H =0.2)

Dips towards road level, and exponentially decreases with height in the canyon

Similar profile has been observed for PM / gaseous pollutants in the past, though others believe the decay is exponential with height.

Many studies are too widely spaced to observe this feature.

Further work is necessary.

Why is this important?

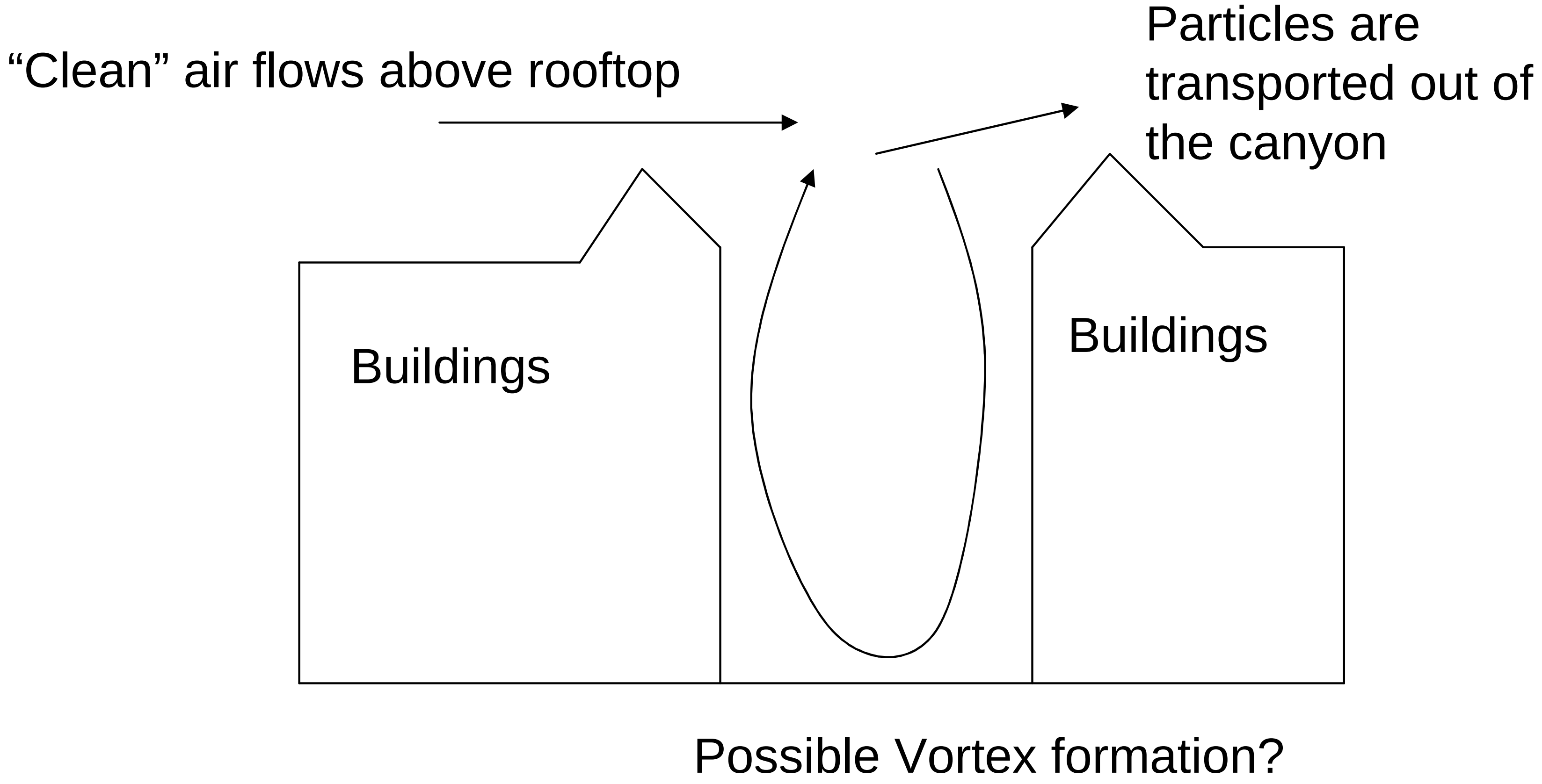
- If the vertical variation of nanoparticle concentration with height is not correctly known, it will not be possible to accurately determine exposure levels for the general population, since sampling often takes place at only one height (and this is frequently high up in the canyon).

Question 2.

- How quickly do ambient particles clear from urban street canyons?

Ventilation Rate

- Ventilation is the process of diluting the air in the canyon with “clean” air from above.



Dependence of PNC on Wind Speed, Traffic Volume and "Background"

$$C_{i-j} = aT^{m}U_{r}^{\,n} + b$$

Concentration in a particular size range

Traffic volume

Windspeed

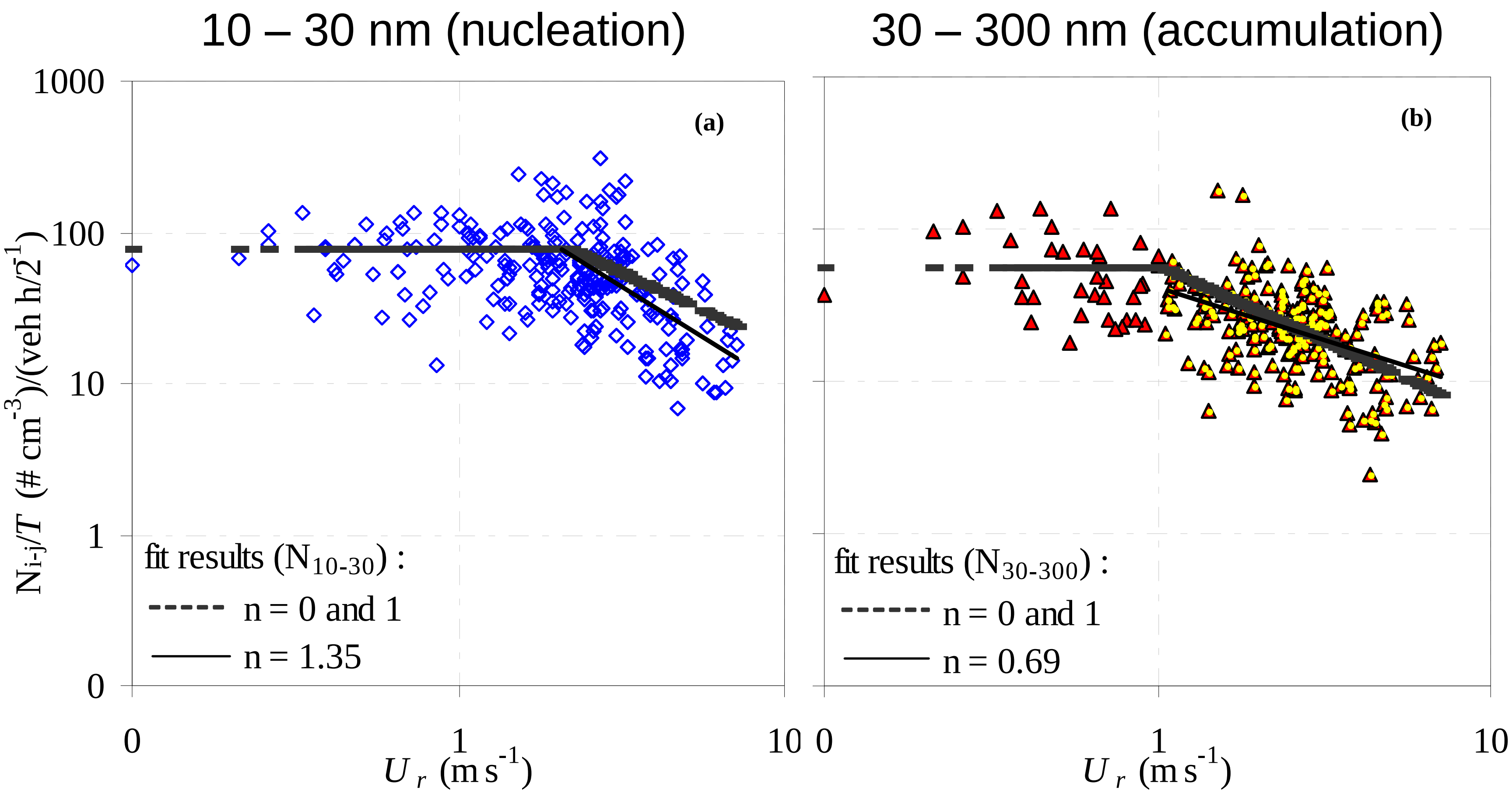
Background

IF particles are emitted in the exhaust of a vehicle (or the dilution and condensation processes in the exhaust are little affected by the ambient conditions):

m = 1, n = -1.

Variation of the Number of Particles with Traffic Volume

- Under almost all circumstances, the number of particles observed is directly proportional to the volume of traffic.
- Possible exceptions include rooftop level measurements, due to the scavenging effect of emissions from traffic on the background particles present.
- To investigate the effect of windspeed and direction on the dilution of particles, the number of particles observed in each 15 minutes was divided through by the volume of traffic in that quarter of an hour.



Plotted above is particle count per unit volume of traffic plotted logarithmically against the windspeed, for winds from the SW (along canyon).

Different methods of fitting the model to the data were tested; it was found that the best model was one which split the measurements into a wind independent (n = 0) and a wind dependent (n=-1) regime.

Minimising the difference between the model and the experimental results yielded the critical windspeed.

Canyon Ventilation

- This means that up till a certain critical windspeed, the dilution processes in the canyon are approximately independent of the above rooftop windspeed. Here, traffic-induced turbulence probably governs dilution.
- Above the critical value, the dilution is proportional to the windspeed, so wind-induced turbulence governs dilution of particles.
- The critical value is higher for smaller particles (10 – 30 nm) than for larger ones (30 – 300 nm), a fact which requires further study.

Conclusions

- The dispersion of ambient nanoparticles is complicated by an urban setting.
- Time-resolved measurements over a broad spectrum of particle sizes allows much more detailed modelling of dispersion, dilution, deposition and transformation processes.
- The concentration of particles is maximal at around breathing height.
- A model where concentration is independent of windspeed up to a critical windspeed and inversely proportional to windspeed thereafter fits our measurements best.

Acknowledgements

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- Workshop, Chemical Engineering (disruption!).