Effects of urban form on air quality


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Topics:

1. Effects of urban vegetation on **city-wide air quality**.

2. Effects of vegetation on **street-level air quality**.

3. Effect of **variable urban roughness** in an operational AQ model.

4. **Scaling laws**: the fourth spatial dimension for cities.
The built land surface can affect air pollutants in four ways:

1. Trapping pollutants in the urban canopy (fumigation)
2. Producing swirls and eddies in the air that mix pollutants away from the ground (vertical mixing); and
3. Slowing the horizontal wind and so reducing the rate of movement of pollutants away from a source (horizontal dilution)
4. Transfer of pollutants from the air to the surface (deposition)
**Urban form II**

Green Infrastructure can affect air pollutants in all of the previous ways and in two additional ways:

1. Emitting volatile organic compounds (VOCs) that form **ozone**
2. Making **space for cleaner air**
Overall city-wide effect, by species:

**Urban Tree Air Quality Score**

- **Greatest capacity to improve air quality**
  - Ash
  - Common alder
  - Field maple
  - Larch
  - Norway maple
  - Scots pine
  - Silver birch

- **Small capacity to improve air quality**
  - Apple
  - Cherry laurel
  - Common elm
  - Common lime
  - Elder
  - Grey alder
  - Hawthorn
  - Hazel
  - Holly
  - Italian alder
  - Lawson cypress
  - Leyland cypress
  - Lilac
  - Mountain ash
  - Sycamore
  - Wild cherry

- **Potential to worsen air quality**
  - Crack willow
  - English oak
  - Goat willow
  - Poplar
  - Red oak
  - Sessile oak
  - White willow

www.es.lancs.ac.uk/people/cnh/UrbanTreesBrochure.pdf
Green walls can be much more effective than previous calculations predicted...(central London example)

...and can have effective cleaning of air in a single canyon (localism). Bottom-up policy becomes possible. Political traction.

Can’t calculate residence time as function of green infrastructure (yet) – so explore model parameter space

- Flat green city
- Filtered avenues
- Flat grey city
- Fumigated avenues

Single street; central London emissions
NERC URGENT programme (2001)
http://www.es.lancs.ac.uk/people/cnh/UrbanTreesBrochure.pdf

Trees & Design Action Group (2012):
http://www.tdag.org.uk/trees-in-the-townscape.html

Reducing roughness increases ground-level pollution in model.
Scaling laws: The fourth spatial dimension of cities

With Matt Barnes, Duncan Whyatt, Nick Hewitt
The fourth spatial dimension of 4837 UK settlements

Variability in the form and function of settlements

Scale-invariant form & function

n = 4837; \( r^2 = 0.71 \)
\( \alpha = 0.91 \)

Modest “economy of scale” when considering all UK settlements
NO\textsubscript{x} emissions

137 Cities, $\alpha = 1.04$

1. Bognor Regis
2. Scarborough
3. Southport
4. Eastbourne
9. London

104 Birmingham
134. Guildford
135. Newport
136. Slough
137. Grays Thurrock

Residues

Rank

Worse than expected
Better than expected
Conclusions:

1. Urban vegetation can have a significant negative effect on boundary-layer air quality in summer smog conditions.

2. Extra-canyon vegetation acts across the whole boundary layer, with small positive effects on street-level air quality.

3. Deposition can be very important for air quality in combination with built forms which trap air at ground-level.

4. Operational AQ models are improved by inclusion of spatially varying roughness but should not be used to investigate urban breathability.

5. No urban AQ models capture all of these effects simultaneously. Need to move beyond locally 1-D land-atmosphere coupling.

6. Fractal scaling operates for UK settlements and highlights winners/losers independent of scale.
Cities are built for people
(or at least to exploit the potentials people offer, fuelled by single-use of natural resources)

http://www.redbubble.com/people/cameracrack/works/825377-busy-city

http://flickrhivemind.net/Tags/zebraxing
Responsive and resilient cities are for life, not just for people (and certainly not just to exploit the potentials people and/or finite natural resources offer).

Image courtesy of The Woodland Trust
Thank you for your attention


Extra slides: not shown
The fourth spatial dimension of 360 US cities

\[ Y(t) = Y_0 N(t)^\alpha \]

\( \alpha = 1.15 \)

- \( \alpha < 1 \): economies of scale
- \( \alpha = 1 \): proportionality
- \( \alpha > 1 \): increasing returns for scale

The fourth spatial dimension measures the self-similar fractality of urban organisation. UK settlements have a shape halfway between a line and a solid plane.
The scaling law does not work for mean concentration
The scaling law depends on the number of settlements chosen.
**Sources of Volatile Organics**

**Biogenic**

- Tree emissions depend on:
  - Species
  - Light
  - Temperature
  - Time of day (circadian)
  - Environmental stress

**Anthropogenic**

- Vehicle emissions depend on:
  - Engine size & type
  - Speed
  - Ambient & engine temperature
  - Driver behaviour

- Anthropogenic emissions include:
  - Alkanes
  - Alkenes (inc. Ethylene & Isoprene)
  - Acetylene
  - Aromatics (benzene, etc)
  - Aldehydes (inc formaldehyde)
Often a well-mixed box is used for atmospheric chemistry simulations. Calculate **1-2% air pollutant reduction** due to urban vegetation. Enough to make a significant contribution to **cost-benefit analysis** – similar analyses used by city mayors in NY and London to embark on tree planting.
Dry deposition in canyon

\[ C = f(E, M, D) \]

How do mixing and deposition interact?

<table>
<thead>
<tr>
<th>Surface</th>
<th>Typical NO(_2) (V_d) (cm s(^{-1}))</th>
<th>Typical PM(_{10}) (V_d) (cm s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete/Brick</td>
<td>0.015 - 0.05</td>
<td>0.02 (vertical)</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.3</td>
<td>0.64</td>
</tr>
</tbody>
</table>
CiTTy-Street model parameterises air circulation in street canyons...

**cartoon**

**model**

**Reality check on model**

![Diagram showing air circulation in street canyons](image)

- **a**: Cartoon of air circulation in a street canyon
- **b**: Graph showing normalized NOx concentration anomaly vs. wind speed
- **c**: Model diagram with components like Upper Compartment, Lower Compartment, and background concentrations
Deep green canyons can even produce better air quality than shallow canyons under some conditions...and the action of all green canyons is to buffer against low-windspeed pollution events.

The influence of in-canyon deposition on vegetation increases at low wind speeds.
When the pollution source is in the street canyon, trees can cause **fumigation**. Without traffic, trees can produce **filtered avenues**, in which air is cleaner than on regional scale.
Example for NO$_2$ (single street central London): too polluted for trees to make a positive contribution.

NB: in-canyon greening always beneficial if no street emissions.

▷ **Local activism** to increase greening should also try to decrease traffic emissions.
Effects of land-atmosphere interactions on air pollution: Operational modelling

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Raster 2013. An Ordnance Survey/Ecina supplied service
Variable roughness improves operational modelling

<table>
<thead>
<tr>
<th>Definition of surface roughness parameter</th>
<th>Proportion of points within a factor of two of the observed data (FAC2)</th>
<th>Mean Bias (MB)</th>
<th>Mean Gross Error (MGE)</th>
<th>Normalised Mean Bias (NMB)</th>
<th>Normalised Mean Gross Error (NMGE)</th>
<th>Root Mean Square Error (RMSE)</th>
<th>Pearson Correlation coefficient (r)</th>
<th>Index of Agreement</th>
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</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>100%</td>
<td>9.4</td>
<td>9.8</td>
<td>0.21</td>
<td>0.22</td>
<td>13.8</td>
<td>0.67</td>
<td>0.07</td>
</tr>
<tr>
<td>Variable</td>
<td>100%</td>
<td>5.8</td>
<td>6.8</td>
<td>0.13</td>
<td>0.15</td>
<td>9.6</td>
<td>0.72</td>
<td>0.35</td>
</tr>
</tbody>
</table>
Effects of land-atmosphere interactions on air pollution: a thought experiment
Sometimes we seem to begrudge space given to green in cities.

Heart of Slough development, 2011. Image courtesy of Giles Charlton, SpaceHub Design.

Is this sustainable?