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Modelling the Impact of Meteorological Conditions Affecting Urban Air Quality

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Introduction

Air pollution is currently estimated to reduce average life expectancy in the UK by 7-8 months and cost the UK in excess of £20 bn per year [1]. There are a variety of UK and EU limits on emissions but these are often breached. When measures to abate the problem are put in place, how do we know that they will work and that limits will be met? This is where prediction using air quality models is crucial. A simple box model approach will be used as a tool to demonstrate the main meteorological processes affecting air quality in an urban environment.

Air pollution over London with the BT tower in the foreground.
(The Guardian, 10 April 2012)

A Box Model of NO_x Concentration

The Model

During the ClearfLo project [2], meteorological and chemical measurements were made in London and its surrounding rural areas. The measurements were used as inputs to an Eulerian box model to predict NO_x concentration c in London, and were compared to measured NO_x concentration at the top of the BT tower. The meteorological input parameters were boundary layer height H, concentration of NO_x both upstream of London c_b and aloft of London's boundary layer (BL) c_a, and wind speed v. A NO_x emission term q was estimated from time series of traffic count data across London. A schematic of the box model is given in Figure 1. The model assumes that NO_x is mixed homogeneously throughout the box, that NO_x is chemically inert, and that no wet or dry deposition occurs.

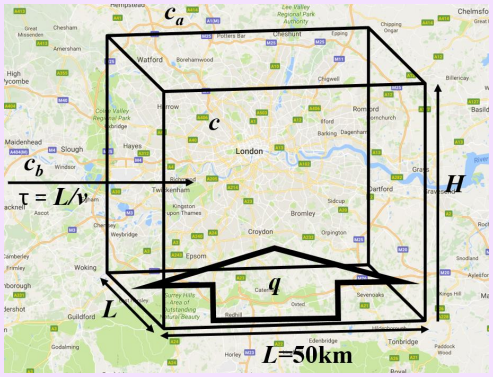

Figure 1: A schematic of the box model for NO_x concentration in London. c is the pollutant concentration in the box, and $\tau = L/v$, the time it takes a parcel entering from upstream of London with concentration c_b, to travel the length L of the box.

Results and Conclusions

Figure 2 shows the model inputs and the results from a case study 11th-17th Aug 2012.

- When q peaks during the morning and evening rush hours, which coincides with lower H since there is less sensible heating, there are predicted and measured peaks in NO_x concentration.
- Large measured peaks in NO_x concentration are observed but not predicted on 12th and 15th corresponding to periods of easterly winds. It is known that emissions are typically greater in East London [3].

We can conclude that when modelling air pollution, it is important to account for spatial variation in emissions and transport of pollutant.

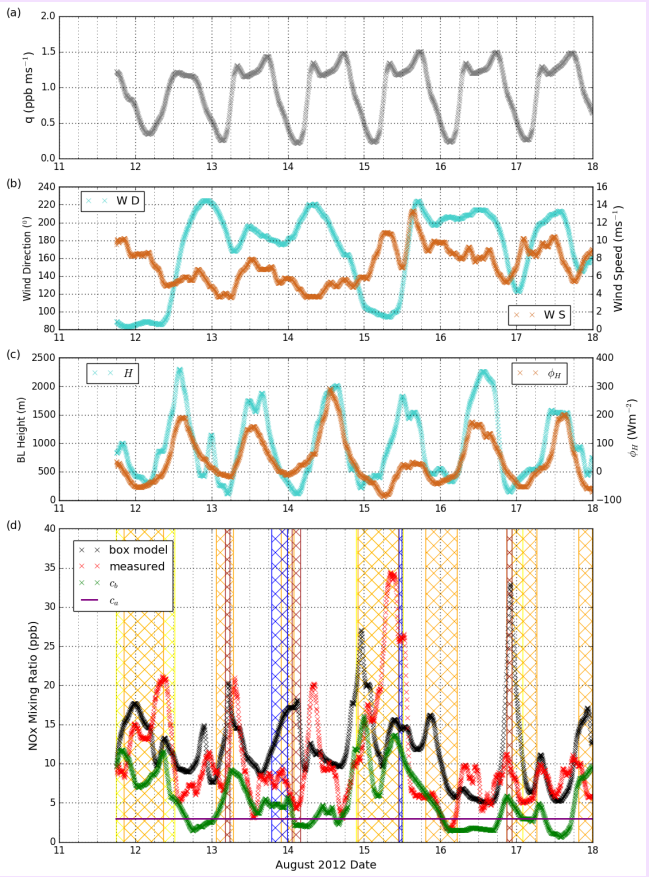

Figure 2: (a) q time series, (b) wind speed and direction time series measured at the top of the BT tower, (c) BL height time series measured using a Doppler Lidar and sensible heat flux $\emptyset_H$ measured using the eddy covariance technique at the BT tower, and (d) time series of c_b, c_a, and measured and predicted NO_x. Areas hatched in yellow have easterly wind direction. Areas hatched in orange have negative $\emptyset_H$ which is indicative of stable conditions when air in the BL is not well mixed. Areas hatched in brown indicate when H was lower than the height that NO_x measurements were taken. Areas hatched in blue indicate when precipitation was observed. When the plot is not hatched (and the box model is expected to perform best) c is within 50% of the measured NO_x measurements 73% of the time.

Ongoing Work

The Met Office is currently carrying out research into O(0.1-1km) urban models where turbulence is partly resolved. In the future air quality forecasting could be based on an application of one of these. I will be using their Unified Model at O(0.1-1 km) resolution to:

- **Determine how model resolution and turbulence scheme affect pollution dispersion**
- **Conclude which meteorological processes most affect pollution concentration**

References

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[2] Bohnenstengel, S. I., et al. "Meteorology, air quality, and health in London: The ClearfLo project." *Bulletin of the American Meteorological Society* 96.5 (2015): 779-804.
[3] Lee, J. D., et al. "Measurement of NOx Fluxes from a Tall Tower in Central London, UK and Comparison with Emissions Inventories." *Environmental science & technology* 49.2 (2014): 1025-1034.

Acknowledgments

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