5.33 DAPPLE - INITIAL FIELD AND WIND TUNNEL RESULTS

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BACKGROUND

DAPPLE is a £1.5M EPSRC funded consortium project that addresses the concerns of the EPSRC Infrastructure and Environment Programme for sustainable urban environments. It brings together a multidisciplinary research group from six leading universities (Bristol, Cambridge, Imperial College, Leeds, Reading and Surrey) that is capable of undertaking monitoring and tracer experiments in the field, carrying out wind tunnel and computational modelling of flow and dispersion and computational modelling of traffic movement and emissions. Its key aim is to enhance understanding of street and neighbourhood scale pollutant dispersion processes in realistic urban environments and thereby make possible improvements in predictive ability that will enable better planning and management of urban air quality. Specifically, DAPPLE aims to quantify determinants of human exposure to air pollution from outdoor sources, over short periods of time as sources and people move together through the urban environment, as well as over longer periods of time in roadside buildings and the urban environment in general. The basic understanding gained will be used in the evaluation and development of appropriate decision support tools and risk assessment methodologies and best practice guidelines for their application, and in assessing the inherent uncertainty in their use and their contribution to the sustainable development of safer, more pleasant cities.

The context of the research is a network of streets characterised by relatively short straight sections between intersections, which is considered to be more representative of central London than a description in terms of street canyons. Previous work (Robins et al, 2003) identified the complex interactions and exchanges that occur at intersections and paved the way for work being carried out within DAPPLE. In this paper we summarise the results from the first field campaign that took place in the spring of 2003, in particular on the day of a tracer release (May 15th), and wind tunnel studies that were undertaken to support the field work and to characterise dispersion behaviour at the field site.

METHODS

The field site, Figure 1, is located in central London in the vicinity of the intersection between Marylebone Road and Gloucester Place. The site was in use between April 28th and May 23rd 2003, during which time a network of instruments operated to monitor traffic movement, air quality, weather, wind and turbulence. Traffic flow data was provided from the 'SCOOT' system used centrally to optimise the control of traffic light operations. Instrumentation mounted mainly on lamp-posts included ten 'street boxes' measuring CO concentrations and seven ultrasonic anemometers, supported by one street mounted and two roof mounted automatic weather stations. Additional meteorological information and forecasts were regularly provided by the UK Meteorological Office. Regular measurements of personal exposure to particle and CO pollution were made during 40 minutes periods at three fixed times each working day. Five modes of transport were covered: foot, bicycle, car, taxi and bus. Two routes were used, one along busy streets and the other including extensive sections along 'back-streets'. Video and voice records were included to provide commentary. Comprehensive measurements of a range of pollutants were available from two fixed monitoring sites in Marylebone Road, close to the field site.

A tracer study was carried out on May 15th at 5pm in the evening. This involved a 15 minute release of SF6 and the perfluorocarbon PMCH from a small source located in a side street (York Road) to the south west of the main site. Ten, three minute air samples were collected at each of ten sampling locations between about 75 and 500m from the source. One sampler was at roof level, with all others at street level. Samples were analysed off-line by NICI mass spectrometry.
Wind tunnel studies were carried out in the 20x3.5x1.5m EnFlo wind tunnel at the University of Surrey. A 1:200 scale model of the site and its immediate vicinity was installed in the wind tunnel. The approach flow boundary layer was neutral and 1m deep, with properties typical of a suburban region. Dispersion behaviour was investigated for a range of continuous and finite duration emissions from point sources in York Street. A single wind direction, from the south west, was studied. Concentration measurements of emitted hydrocarbon were made using conventional and fast flame ionisation instrumentation (frequency response about 250Hz).

RESULTS
On May 15th winds began light and from the south-south west (200 degrees). The direction remained constant but wind speed gradually increased during the day and reached 3.5ms^{-1} at 5pm when the tracer experiment took place. These results refer to a reference automatic weather station mounted on the roof of Westminster Council Hall at 15m. Weather conditions were fair with broken cloud and sunny spells.

CO measurements on either side and in the centre of Marylebone Road showed that a characteristic canyon-like circulation developed during the afternoon. Concentrations at a height of 3m on the south side of the street were a factor of 3 to 4 larger than at the same height on the north side of the street. With winds in this direction there was also a well defined vertical structure to CO concentrations with values at a height of 7m approximately 75% those at 3m.

The roof-top wind direction of SSW induced a northerly directed mean flow in Gloucester Place and an easterly directed flow along Marylebone Road. Measurements at the intersection showed a bimodal distribution of wind directions as the flow switched between being northerly and easterly directed. Such unsteadiness was an obvious feature of earlier wind tunnel studies of dispersion at an intersection (Robins et al, 2003). On other occasions at the field site, street level winds were seen to switch by 180 degrees, say from north to south in Gloucester Place as the roof level wind direction moved from just south to just north of westerly.

Results for the PMCH tracer release are shown in Figure 2 as non-dimensionalised concentrations, CU_HH^2/Q, where H is the mean roof height (22m), U_H the roof level wind speed (3.5ms^{-1}) and Q the emission rate (114mg in 15 minutes). The concentration values used here are the maximum three minute mean observed at each sampling location. A complex pattern of transport along streets and transfer at intersections is apparent. Of particular interest is the zero reading at sampling locations 1 in York Road and 8 in Marylebone Road. Later wind tunnel simulations of the field experiments showed that transport along York Street to location 1 was intermittent, in some cases leading to the observed zero concentration. Concentrations at locations 4 and 5 were almost the same, even though one location was at street level and the other at roof level. The decay of concentration with distance could be fitted by a R^{-2} dependence, where R is the straight line separation between source and receptor; the reason for using this decay law is to be found in the wind tunnel data described later. The travel time to locations 4 and 5 was about 4.5 minutes,

implying a mean transport speed of about $0.5ms^{-1}$. However, with a sampling interval of three minutes there is really insufficient resolution to extract travel times and consequently this result is not particularly reliable.

Wind tunnel experiments treated both continuous and finite duration emissions. In the former case, ground level concentrations were mapped over the street network for a range of source positions in York Street. Additional measurement provided vertical profiles and distributions above roof level. Figure 3 shows a compilation of all the wind tunnel ground level concentration data, non-dimensionalised as $CU_{ref}H^2/Q$, where U_{ref} is the reference speed at the boundary layer edge plotted against separation, R/H. There is a clear upper bound to this data that can be expressed as:

$$CU_{ref}H^2/Q = 50(R/H)^{-2}$$

An interesting thing about this empirical result is that the concentration is actually independent of the building height. A similar result has also been found from similar measurements in regular arrays of rectangular obstacles and in the Salt Lake City experiments reported by Hanna et al (2003). Interestingly, the constant turns out to be much the same in all three cases.

A variety of finite duration emissions between 0.5 and 10s was used to investigate travel, rise and decay times. Ensembles of order 100 emissions were used to define mean concentration distributions as functions of time after release and distance. A single realisation and the ensemble average may differ considerably; e.g. a peak concentration in a single realisation may be more than four times larger than the maximum of the ensemble average. Clearly, knowledge of the mean distributions, as would be predicted by most dispersion models, would be of little value in determining the potential hazard that such an emission might pose.

Travel times were measured from the start of the emission to the time at which the concentration record reached 50% of its upper limit; rise and decay times were measured between the 25% and 75% points of the rising and falling edge. This led to a linear increase in all three time scales with increasing distance, such that:

$$U_{ref}T_{50}/H = 7.5(R/H); \qquad U_{ref}\Delta T_{50}/H = 2.5(R/H)$$

where T_{50} is the travel time and ΔT_{50} the rise and decay times. This implies that the mean travel speed is $U_{ref}/7.5$ and that the rise and decay times are about 1/3 of the travel time. These results can be written in terms of the roof level wind speed by noting that U_H is approximately 50% of U_{ref}.

CONCLUSIONS

For source-receptor separations up to about 20, both field and wind tunnel results show that the maximum concentration at distance R from a source decays as R^{-2}, implying that concentrations are independent of building height. Travel speeds of pollutant clouds within the street network are about $U_H/4$ and rise and decay times about 1/3 of travel times.

The next period of field measurements will be in the spring of 2004. Amongst other things, further tracer studies will be undertaken. Experimental capabilities have been extended so that three different perfluorocarbons will be released simultaneous from different source positions during these studies.

REFERENCES

Hanna, SR, Britter, R & Franzese, P, 2003. A baseline urban dispersion model evaluated with Salt Lake City and Los Angeles tracer data. Atmos. Environ., 37, 36, 5069-5082

Robins, AG, Savory, E, Scaperdas, A & Grigoriadis, D, 2002. Spatial Variability And Source-Receptor Relations At A Street Intersection. Water, Air, & Soil Pollution: Focus, Volume 2, Issue 5-6, 381-393

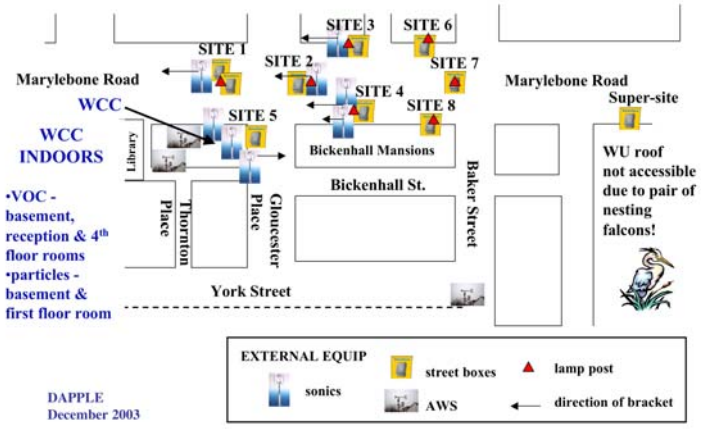

Figure 1. Site map showing deployment of instrumentation.

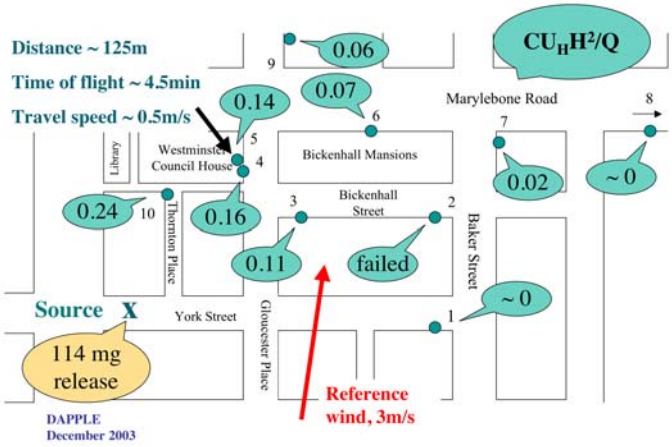

Figure 2. Results from the tracer study shown as non-dimensional concentrations.

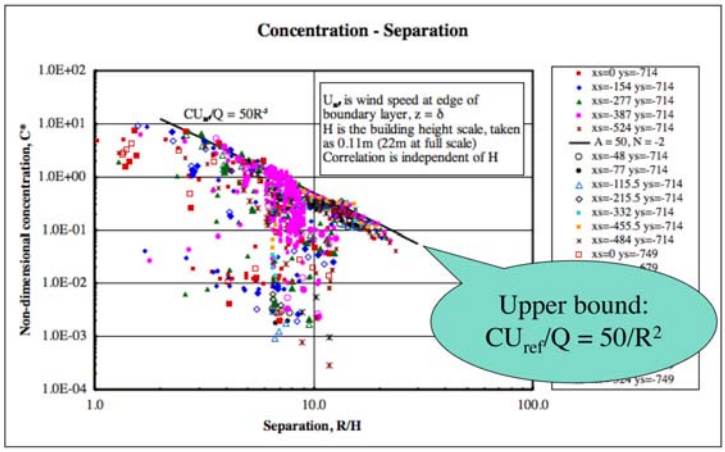

Figure 3. Mean concentration data from wind tunnel modelling with south west winds.